REDISTRIBUTION AND MOBILIZATION OF NUTRIENTS AS A RESULT OF HARVEST AND SITE PREPARATION OF A PINE FLATWOODS FOREST

By

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To my wife, Sue Ann

and my entire

family

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation presented to the Graduate Council of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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The impacts of intensive and less intensive systems of forest management on nutrient distribution and mobilization were investigated following harvest, preparation, and regeneration of a flatwoods pine site in north-central Florida. The intensively managed site was mechanically harvested and prepared for planting by chopping, stumping, burning, KG-blading, harrowing, and bedding operations. The less intensively managed site was harvested by logging crews using chain saws. Residual vegetation and slash were reduced prior to planting by chopping and bedding.

Nutrient removal associated with the bolewood harvest was similar on the two sites. Estimated removals of N, P, K, Ca, and Mg were 85, 17, 25, 102, and 19 kg/ha, respectively. In the intensively prepared site, an additional 373, 18, 27, 163, and 41 kg/ha of N, P, K, Ca, and

Mg were redistributed into windrows during the KG-blading operation. Most of these nutrients were associated with the soil component of the windrow.

The storage of nutrients in litter and residual logging slash was severely depleted on the intensively prepared site. Slash and litter storage of N, P, and K averaged only 22, 1, and 1 kg/ha, respectively, following intensive preparation. Similar storages on the less intensively prepared site were an order of magnitude larger.

Bedding effectively concentrated nutrients into the seedling rooting zone on both sites. The N, P, K, Ca, and Mg contents of the surface soil of the beds were 50% greater than in the interbed areas of the plantation. Most of this increase was due to increases in the depth of the surface soil.

Inorganic N concentrations in the soil solution increased during the spring following harvest on both sites and remained at elevated levels throughout the treatment and first post-treatment years. Peak NH_4-N and NO_{23}-N concentrations of 2.12 and 4.08 ppm occurred in the intensively prepared site. No significant increases in PO_4-P concentrations were noted on either site.

The short term impacts of intensive site preparation were favorable. First year seedling survival approached 90% on the intensively prepared site as compared to 75% survival in the less intensively prepared area. Height growth was also greater on the intensively prepared area. It was suggested that increases in N availability associated with increases in the pool of mineralizable N and N mineralization rates contributed to more favorable growth conditions on the intensively prepared site. It appeared unlikely that these increases in N avail-

ability would be maintained past the first growing season due to the paucity of litter and slash which could serve as a source of organic N for replenishing the pool of mineralizable N

INTRODUCTION

The pine forests of the southeastern United States are among the more productive forests in the world. Over 115 million m^3 of roundwood fiber are harvested from this region annually, accounting for 45% of the total U.S. softwood fiber production (U.S. Forest Service, 1980). Recent projections indicate that this figure will increase to 175 million m^3 by the year 2030 (U.S. Forest Service, 1980). This forecast was made in spite of the fact that the total acreage of forest land in the Southeast has been declining for the last 10 years and is expected to continue to decline in the foreseeable future (Forest Industries Council, 1980). Thus, the predicted yield increases will only be achieved through more intensive management of, and increased fiber production from, the available forest lands.

Intensive forest management, which utilizes heavy machinery both to harvest the stand and to mechanically prepare the site prior to planting, has been an accepted practice of southern pine management for 20 years. Improved seedling survival and increased growth have been demonstrated on intensively prepared sites for both loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) over a range of sites from the Piedmont (Haines, 1978) to the wet savannahs of the coast (Pritchett and Smith, 1974; Terry and Hughes, 1975, Pritchett and Fisher, 1980). Site preparation is widely used in the pine flatwoods of the lower Coastal Plain where the low relief, sandy soils, and large

block ownerships combine to make these sites favorable for mechanized operations.

There is considerable concern that the benefits of some intensive management practices are short termed and that they may lead to a decline of productivity in future rotations (Haines et al., 1975; Pritchett and Wells, 1978). This concern largely results from reports of declines of productivity in second rotation conifer plantations in Australia (Keeves, 1966), New Zealand (Stone and Will, 1965), Europe (Weidemann, 1923, Evans, 1976), and Africa (Evans, 1976). The cause or causes of these declines are not entirely clear. Changes in microorganism populations, deterioration of soil physical properties, increased understory competition, and reduced water availability have all been suggested as possible causes, but the most frequently suggested cause has been nutrient depletion (Wells et al., 1975).

Declines in productivity similar to those reported in other countries have not been documented in the United States. Nevertheless, our concern appears well founded. The southern pine region falls within three physiographic provinces: the Appalachian Piedmont, the Gulf Coastal Plain, and the Atlantic Coastal Plain. The soils of these regions are characterized by low nutrient reserves. The capability of these soils to provide individual nutrients over several rotations, and the demand placed upon that capability by intensive management practices, has not been adequately investigated. Even less is known about the impact of intensive site preparation on mineralization and nutrient availability during plantation establishment.

The objectives of this investigation were to

1. Quantify nutrient contents and distribution in a natural pine flatwoods ecosystem in the Coastal Plain.

2. Quantify nutrient removal, translocation, and loss associated with varying intensities of harvest and site preparation and evaluate these losses in the context of the capability of the site to supply nutrients over several rotations.

3. Investigate the physical and chemical changes which occur in the surface soil of harvested and prepared sites and relate these changes to seedling nutrition and to the export of nutrients from the site.

LITERATURE REVIEW

Nutrient Distribution and Cycling in Forest Ecosystems

General

Documentation of declines in site productivity over several forest rotations has proven difficult. Differences in stocking rates, tree genotypes, and management practices such as drainage, fertilization, and site preparation have limited the usefulness of direct comparisons of yield data from successive rotations. Comparisons of yield from forest stands which were managed by different methods have proven helpful, but have been restricted to use where stands occurred on similar soils, were regenerated from the same seed source, and for which accurate records were available. Since locations which meet these restrictions are limited, investigators have had to approach the problem indirectly. One approach which has proven useful is ecosystem analysis (Ovington, 1962). Ecosystem analyses utilize measurements of nutrient storage, inputs, exports, and internal cycling as a basis for making inferences about the effects of management activities on site productivity.

A reasonably large data base on the distribution and cycling of nutrients in some important forest ecosystems now exits, however, care must be exercised if misleading interpretations of these data are to be avoided. Interpretation of soil nutrient reserves are particularly

troublesome. Calculations of nutrient reserves on the basis of instantaneous soil tests of the surface horizons as are commonly reported, do not reflect the depth to which trees root nor do they reflect the chemical processes by which nutrients become available to the tree (Stone, 1973). Our knowledge of nutrient inputs and exports is also limited. Thus, conclusions reached on the basis of these data must be considered tentative until tested in a more systematic manner.

Nutrient Distribution in the Major Forest Biomes

Excellent reviews of the literature on nutrient distribution and cycling in the major forest biomes are available. General reviews of nutrient cycling in the boreal (Krause et al., 1979), temperate (Ralston, 1979), and tropical (Cole and Johnson, 1979) forest biomes were recently published in the proceedings of the Fifth North American Forest Soils Conference. More complete reviews of the available literature on specific forest ecosystems are also available, the reviews by Duvigneaud and Denaeyer-DeSmet (1970) on the distribution and cycling of nutrients in deciduous forests of Belgium, and the tropical rain forests of Central America by Golley et al. (1975) are particularly noteworthy.

The distributions of nutrients in representative mature forest stands within the boreal, temperate, and tropical forest biomes are presented in Table 1. Variability between stand types within each biome is large and tends to mask differences in total nutrient content between the biomes. Comparatively larger quantities of N, P, K, Ca, and Mg are stored in the vegetation of tropical forests and in the forest floor of boreal forests.

Table 1 Nutrient content and distribution in major forest biomes

Forest type	Vegetation					Forest floor					Mineral soil					Source
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg	
	kg/ha															
							BOREAL									
Black Spruce	111	11	86	211	11	1211	231	282	102	130	286	160	16 001	1 111	1 115	Weetman and Webber (1972)[a]
Spruce-Fir	381	11	111	111	16	1415	100	1051	111	156	159	114	9 381	161	1,121	Weetman and Webber (1972)[b]
Jack Pine	111	11	01	114	11	328	13	516	341	116	1129	1180	101 334	11 100	32 011	Foster and Morrison (1911)[c]
Jack Pine	116	21	116	196	12	344	10	11	156	11	1151	495	500	1 127	101	Green and Grigal (1180)[d]
							TEMPERATE									
Mixed Oak	411	12	261	060	61	11	1	15	31	1	1111	911	11 000	151 100	1 460	Duvigneaud and Denaeyer-DeSmet (1970)[e]
Beech	201	11	181	152	43	180	11	70	51	11	6660	12	154	315	110	Ovington (1962)[f]
Mixed Broad-leaved Pine	111	18	31	111	44	211	11	11	134	10	1498	10	01	601	01	Burger (1119)[g]
Douglas-fir	121	61	111	361	80	111	26	31	117	80	1109	1178	134	141	NR	Cole et al. (1011)[h]
							TROPICAL									
Celtis zenkeriana	1530	101	702	1110	111	111	31	106	530	11	4112	11	650	2 519	1 491	Greenland and Kowal (1160)[i]
Cavanillesia-Hura	80	241	1598	1702	411	NR	NR	NR	NR	01	NR	11	180	10 502	1 833	Golley et al. (1111)[j]

[a] Overstory vegetation only; soil depth to 31 cm (rooting depth); soil cations determined by HF/HClO$_4$ digestion
[b] Overstory vegetation only; soil depth to 18 cm (approx. rooting depth); soil cations determined by HF/HClO$_4$ digestion
[c] Soil depth to 100 cm; soil cations determined by HF/HClO$_4$ digestion
[d] Soil depth to 100 cm; soil P determined by Bray No. 1; soil cations by NH$_4$OAc extraction
[e] Forest floor includes leaf litter only; soil to 40 cm depth; totals by unspecified digestion
[f] Soil depth to 10 cm; P and cations extracted using H$_2$SO$_4$/HClO$_4$/HNO$_3$ digestion
[g] Soil depth to base of B$_2$ horizon (approx. 80 cm); soil P and cations determined by H$_2$SO$_4$/HCl extraction
[h] Soil depth to 60 cm; P by H$_2$O$_2$/H$_2$SO$_4$ digestion; cations by NH$_4$OAc extraction
[i] Forest floor includes "litter" and "roots"; soil depth to 30 cm; soil P by Truog; cations by extraction in NH$_4$OAc
[j] Soil depth to 30 cm; soil P and cations by H$_2$SO$_4$/HClO$_4$/HNO$_3$ digestion

The nutrient reserves in the forest floor and mineral soils of mixed slash pine-longleaf pine (Pinus palustris Mill.) stands are low in comparison with other ecosystems. Only the N reserve of black spruce (Picea mariana (Mill.) B.S.P.) stands growing over bedrock (Weetman and Webber, 1972) were lower than the N reserve reported by Burger (1979). The content of soil P reported by Greenland and Kowal (1960) for a tropical ecosystem was lower than the content of soil P reported by Burger, but it was based on a soil depth of 30 cm whereas Burger's values were based on a soil depth of approximately 80 cm. The total ecosystem contents of K, Ca, and Mg reported by Burger are lower than any other reported values.

Nutrient Fluxes of Undisturbed Forest Ecosystems

The characterization of nutrient fluxes in a forest ecosystem establishes a baseline by which the effects of nutrient removal or loss associated with harvest and site preparation can be assessed. These fluxes have been considered as belonging to either a biological or geochemical nutrient cycle (Remezov, 1959, Duvigneaud and Denaeyer-DeSmet, 1970). In fact, no such distinction exists. As Mälkönen (1974) has pointed out, the biological cycle is merely a link within the geochemical cycle which modifies the transfer of nutrients from the sea and atmosphere to the ecosystem. This is exemplified by the role of living organisms in N-fixation and denitrification processes.

Processes which are associated with the flow of nutrients across ecosystem boundaries are of primary significance in evaluating the long term effects of intensive forest management on nutrient reserves.

calculations of transfers within the system, such as associated with litter fall and decomposition, are useful for evaluating short term responses to site disturbance and their effect on tree nutrition.

<u>Sources of nutrient inputs to undisturbed forests</u>. Essential plant nutrients can enter a forest ecosystem as ions dissolved in rainwater, particulate fallout, trapped aerosols, or directly absorbed and biologically fixed gases. Bulk precipitation inputs, which include both dissolved ions and particulate fallout, have been the most thoroughly documented of these inputs. Wide ranges of values have been reported for all elements. In general, annual inputs of most nutrients are greatest near oceans and decrease inland (Chamberlain, 1975); however, anthropogenic sources may increase concentrations over large regions. Swank and Henderson (1976) reported greater inputs of both cations (Ca, Mg, K, and NH_4) and anions (NO_3 and PO_4) in watersheds which were located near coal burning electric generating stations (Walker Branch) than in watersheds which were located in more isolated areas (Coweeta) within the Appalachian Highlands. Most of the increased inputs at Walker Branch were attributed to dry particulate fallout. The magnitude of bulk precipitation inputs reported for other areas of the Southeast are typically equal to or less than those reported for Walker Branch and are not significantly different from those reported for the heavily industrialized Northeast (Table 2). These inputs are lower than have been reported for industrialized areas in Great Britain.

Nutrient inputs resulting from aerosol impaction, gaseous adsorption, and biological fixation have not been thoroughly investigated. The quantities of aerosols which are trapped by vegetation in excess

Table 2 Annual elemental inputs to forest ecosystem in bulk precipitation

Location	Years of record	Inorganic[a] N	Total N	P	K	Ca	Mg	Source
		---------------	kg ha^{-1} yr^{-1}	---------------				
North Carolina (Coweeta)	3	3.4	ND	0.19	2.6	4.9	1.1	Swank and Henderson (1976)
Tennessee (Walker Branch)	3	7.0	ND	0.55	3.0	15.7	2.9	Swank and Henderson (1976)
New Hampshire (Hubbard Brook)	11	6.7	ND	0.04	0.9	2.2	0.6	Likens et al. (1977)
Oregon (H.J. Andrews)	3	ND	2.0	0.30	0.90	3.6	ND	Sollins et al. (1980)
Florida (Austin Cary Forest)	1	ND	5.6	0.62	3.5	ND	ND	Burger (1979)
Florida (IMPAC Bradford Forest)	3	5.0	7.5[b]	1.10	2.3	4.8	3.1	Riekerk (1981)
Great Britain (Moor House National Forest)	6	14.0[c]	NA	0.85	4.8	13.1	3.2	Gore (1968)

[a] NH_4-N + NO_{23}-N

[b] Less NO_2-N

[c] Four years of record

of those deposited on open ground (and measured in bulk precipitation) are dependent on source locations, wind characteristics, and canopy properties. Morphological characteristics of the vegetation, such as the presence of leaf pubescence, are also important (Chamberlain, 1975). The magnitudes of these inputs are thought to approach those associated with bulk precipitation in most forest ecosystems (Mayer and Ulrich, 1974, Miller et al., 1976). Nitrogen may be directly absorbed by the soil as NH_3 (Ingham, 1950) but it seems unlikely that the contributions from this source are large. As Miller (1978) has pointed out, an exception may be the relatively large NH_3 adsorption in snow covered forest floors of boreal forests.

Inputs of N through biological fixation can be extremely large in forests containing nodulated species. Newton et al. (1968) estimated the N-fixation of red alder (Alnus rubra Bong.) could exceed 300 kg ha^{-1} yr^{-1} in forest stands. However, in most forests these inputs are much lower. Wax myrtle (Myrica cerifera L.), an actinorhizal shrub of the Southeast, has been estimated to fix 3 kg ha^{-1} yr^{-1} by Silver and Mague (1970) and 10 kg ha^{-1} yr^{-1} by Permar (1980)[a] in natural stands of slash pine.

Non-symbiotic N-fixation occurs in both the soil and leaf canopy. Phyllosphere fixation has been estimated for mature Douglas-fir (Jones, 1970, Denison, 1973, Sollins et al., 1980). Comparable research has not been conducted in the Southeast, but can be assumed to be less than the 1 to 3 kg ha^{-1} yr^{-1} reported by these investigators. Non-symbiotic

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[a] Permar, T. A. 1980. Nitrogen enrichment of the pine flatwoods by wax myrtle (Myrica cerifera L.), unpublished M.S. thesis, University of Florida, Gainesville.

fixation in the soil is also [illegible] 1-2 $kg \cdot ha^{-1} \cdot yr^{-1}$ (Wollum and Davey, 1975)

<u>Avenues of nutrient loss</u> Nutrient losses associated with deep leaching and surface runoff are well documented. Cole and Rapp (1981) summarized the results from 14 forest stands which have been monitored in conjunction with the International Biological Program (IBP) and included data from major forest types throughout the world (Table 3). With few exceptions these data indicate that N and P losses from undisturbed forests are small. Annual N losses were less than 4 $kg \cdot ha^{-1} \cdot yr^{-1}$ in all but three sites, and export of P was less than 0.2 $kg \cdot ha^{-1} \cdot yr^{-1}$ in all but one site. The higher values were determined on the basis of leachate collected at less than 100 cm depth in the soil and it is questionable whether they represent ecosystem losses. Measured losses of other nutrients were variable and depended on site characteristics.

Values for soluble N and P losses from undisturbed watersheds in the southern pine region fell within the range of values presented in Table 3. Schreiber et al. (1976) reported that inorganic N losses ranged from 2.1 to 5.7 $kg \cdot ha^{-1} \cdot yr^{-1}$ for five mixed loblolly and slash pine watersheds in Mississippi. Losses of inorganic P and soluble Ca, Mg, and K were low, averaging 0.04, 6.2, 3.1, and 3.3 $kg \cdot ha^{-1} \cdot yr^{-1}$, respectively. Low nutrient exports have also been reported from three natural slash pine stands in a flatwoods landscape of the lower Coastal Plain by Riekerk et al. (1979). Average exports of inorganic N and P, and soluble K and Ca, in surface runoff and deep leaching were 0.6, 0.2, 2.4, and 7.0 $kg \cdot ha^{-1} \cdot yr^{-1}$, respectively.

TABLE 1. Elemental leaching and stream runoff at the IBP study sites.[a]

	Location	Elemental loss				
		N	K	Ca	P	Mg
		kg ha^{-1} yr^{-1}				
Forest type		Leaching				
Douglas fir (100 cm)[b]	Washington	0.6	1.0	4.5	0.02	ND
Picea abies (100 cm)	Russia	0.9	2.2	2.3	0.06	0.5
Spruce (50 cm)	Germany	14.9	2.1	13.5	0.02	3.7
Yellow popular (60 cm)	Tennessee	3.5	8.9	44.5	0.05	NP
Beech (50 cm)	Germany	6.0	2.9	12.7	0.10	3.7
Oak-Birch	Great Britain	12.6	8.3	59.8	0.2	6.0
Red alder	Washington	1.7	ND	2.2	ND	ND
Watershed location		Watershed runoff				
H.J. Andrews	Oregon	1.7	9.7	121.8	0.8	10.7
Coweeta	North Carolina	0.2	4.5	5.9	ND	ND
Hubbard Brook	New Hampshire	3.9	1.9	13.7	0.01	3.1
Walker Branch	Tennessee	1.8	6.8	147.5	0.02	77.1

[a] Source: Cole and Rapp (1981)

[b] Depth at which leachate was collected

Direct estimates of nutrient loss due to erosion are difficult to make. It is generally acknowledged that erosion rates, and the loss of nutrients associated with sediment, are low in forested watersheds (Fredriksen et al., 1975). McColl and Grigal (1979) used data from a number of undisturbed forests in the eastern and western United States to calculate sediment-associated nutrient losses. They estimated losses of N, K, Ca, and Mg to be less than 0.1 kg ha^{-1} yr^{-1}. These losses are much smaller than the reported values for soluble losses of these nutrients. Phosphorus is strongly adsorbed by soil, and unlike other macronutrients, is primarily lost as sediment (Sharpley and Syers, 1979). Research in forested watersheds indicates that P losses associated with sediment can be twice as large as dissolved losses (Duffy et al., 1978) although these losses are still less than 0.2 kg ha^{-1} yr^{-1} (Duffy et al., 1978; Singer and Rust, 1975).

Gaseous losses of N result from biological denitrification and from volatilization during wildfire. As Wollum and Davey (1975) have pointed out, very little information on denitrification processes in natural stands exist. Those studies which have been conducted have generally failed to detect appreciable denitrification. Denitrification losses from flatwoods soils of the Southeast do not appear to be large. Boomsma and Pritchett (1980) failed to detect appreciable denitrification from undisturbed flatwoods forests, and losses following application of 400 kg/ha urea amounted to only 9 kg/ha. In contrast, volatile losses of N during fires can be large. Estimates of such losses range from 855 kg/ha during wildfires in boreal forests (Grier, 1975) to losses of only 26 kg/ha during prescribed burns in young pine plantations in

the southeastern United States (Kodama and Van Lear, 1980). Hot fires can also result in significant losses of non-volatile elements in flyash. For instance, in the aforementioned study Grier estimated that K, Ca, and Mg losses were 282, 75, and 33 kg/ha, respectively.

<u>The nutrient balance of undisturbed forests.</u> Nutrient budgets provide a framework within which the significance of differences in nutrient input and export from forest ecosystems can be evaluated. However, these budgets should not be considered inviolable as they have seldom been based on measured values for all sources of nutrient input and export. For instance, information on 36 sites was reported by Cole and Rapp (1981) but biological N-fixation was estimated for only 2 of the 36 sites and aerosol impaction and denitrification were not estimated for any of the sites. Thus, the nutrient balances reported for these ecosystems, as is the case for most ecosystems, were incomplete.

Nitrogen tends to accumulate in forest ecosystems between fires or other disturbances. Exceptions occur in localized areas, such as reported for the Merlewood Research Station in Great Britain (Cole and Rapp, 1981), but these are unusual. The fluxes of P, K, Ca, and Mg are closely tied to parent geology and both positive and negative net fluxes have been reported. Studies of nutrient budgets of undisturbed southern pine ecosystems growing on infertile sandy soils have indicated that these systems accumulate all major nutrients (Riekerk et al., 1979).

Cycling rates within forest ecosystems vary according to major climatic zones. In their summary of the IBP study sites, Cole and Rapp concluded that

1. The mean residence time of elements in the forest floor varies widely between regions. Turnover periods are longer in the boreal region and significantly shorter in the temperate and Mediterranean regions than in other forest regions. Coniferous forest floors have longer turnover periods than deciduous forest floors.

2. The rate of nutrient uptake and requirement is significantly higher in deciduous forests than in coniferous forests for all elements except P.

3. Deciduous species translocate significantly more N from older foliage before litterfall than do conifers. Very little K is translocated for either coniferous or deciduous species.[a/] Neither Ca nor Mg is translocated, rather the uptake of these two elements greatly exceeds annual requirement for both coniferous and deciduous species.

4. In coniferous species, uptake and requirement of both N and K are strongly correlated with biomass production. The correlation is somewhat weaker for deciduous species in regards to N uptake and requirement.

5. Coniferous species are consistently more efficient than deciduous species in producing biomass with equal amounts of N uptake. Similarly, species in the boreal sites are more

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[a/] This conclusion is not consistent with accumulated evidence. Most investigations have concluded that K is readily translocated within the tree.

efficient than those in the temperate region. Apparently, the efficiency of production per unit of N uptake increases as N becomes more limiting.

The nutrient cycles of 3 forest ecosystems representative of the boreal, temperate deciduous, and temperate coniferous (southern pine) biomes are presented in Table 4. Nutrient cycling rates of slash pine are low in comparison with temperate deciduous forests and are not very different than the cycling rates reported for Jack pine (Pinus banksiana Lamb.) stands in the boreal forest biome. Conservative nutrient cycles, such as this, are typical of pines and enable them to grow on nutrient impoverished soils (Millet et al., 1979).

The Impact of Intensive Harvesting and Site Preparation on Nutrient Budgets

General

Mechanized clearcut harvesting followed by intensive site preparation and machine planting has become the silvicultural mainstay of pine plantation management throughout much of the industrialized world. Mechanical site preparation is almost universal in the pine forests of the lower Coastal Plain where the low relief, sandy soils, and large block ownerships combine to make these sites favorable for mechanized operations.

Excellent general reviews of site preparation objectives, techniques, and offsite consequences are available (Post, 1974, Chavasse, 1974). Site preparation practices specific to the southern pine region have also been reviewed (Haines et al., 1975; Terry and Hughs, 1975, Burger, 1979). The primary objective of site preparation is to increase

Table 4 Nutrient balance and internal cycling of three representative forest ecosystems

Biome Forest type Age	Boreal[a] Jack pine 30					Temperate (deciduous)[b] Mixed oak 75					Temperate (coniferous)[c] Slash pine 45				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	kg/ha														
Storage															
Vegetation	171	15	85	114	19	406	32	245	868	81	174	13	51	148	12
Forest Floor	328	43	524	319	116	ND	ND	ND	ND	ND	256	11	11	134	28
	$kg \cdot ha^{-1} \cdot yr^{-1}$														
Inputs															
Bulk precipitation	7.9	0.1	4.0	5.6	0.8	13.0	ND	5.0	19.0	5.8	5.6	0.6	3.5	16.[illegible]	[illegible]
Outputs															
Runoff	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	0.1	2.8	ND	ND
Deep leaching	ND	ND	ND	ND	ND	4.4	2.6	8.4	T	2.1[d]	0.1	T	0.2	ND	ND
Internal cycling															
Uptake	32	2	18	21	3	92	6.9	69	201	18.6	26	1.5	4	ND	ND
Retention	6	1	3	4	1	30	2.2	16	74	5.6	2	0.2	1	ND	ND
Return	26	1	15	17	2	62	4.7	53	127	13.0	24	1.3	3	ND	ND

a/Source: Foster and Morrison (1976)
b/Source: Duvigneaud and Denaeyer-DeSmet (1970)
c/Source: Burger (1979)
d/Source Cole and Rapp (1981)

seedling survival and growth. The specific aims do, however, very between locations. Burger (1979) summarized these as including

1. Control of competing vegetation and removal of overhead shade,
2. Increase moisture availability by eliminating competing vegetation
3. Facilitate planting by eliminating cull trees and logging debris.
4. Improve wildlife habitat
5. Create a mineral seedbed
6. Reduce compaction and increase soil aeration
7. Control insects and diseases
8. Improve nutrient availability by breaking down and incorporating organic matter into the soil

Early attempts to prepare cutover lands using farm equipment were not very successful (Wilhite, 1961) and were quickly replaced by sophisticated techniques employing equipment specifically designed for forestry operations (Haines et al., 1975). Four basic mechanical operations chopping, harrowing, windrowing, and bedding, are currently used for site preparation in the Southeast. Chopping, which is the least disruptive of these operations, consists of pulling a large drum fitted with radially placed blades across the site to crush and break residual slash. Disk harrowing is often utilized on sites with strongly formed root mats as a means of exposing the mineral soil. Windrowing entails pushing woody vegetation and organic debris into long piles using either a KG-blade or rootrake. This site preparation technique is normally used on sites occupied by heavy hardwood scrub or which are particularly rough and not easily prepared for planting by other methods

The piles are either burned or left to naturally decompose. The bedding operation is the final operation in site preparation and usually follows one of the aforementioned techniques. Raised mounds on which seedlings can be planted are formed during this operation by pulling an hourglass-shaped roller behind inward-turned concave coulters. The bedding operation is the final operation in site preparation and usually follows one of the aforementioned techniques. Approximately 55% of all industrially owned lands in the Southeast are prepared by windrowing, 40% are chopped, 35% bedded, and at least 18% disked (Freeman, 1978).

<u>Harvest Removals</u>

The quantities of nutrients removed under various harvesting regimes have been documented, or can be calculated from data generated by ecosystem studies, for most commercially important forest types. Exhaustive reviews of the available literature on removal rates in short rotation plantations (Hansen and Baker, 1979), medium age forests (Morrison and Foster, 1979), and long rotation systems (Marian, 1979) have been completed in conjunction with a recent symposium on the impacts of intensive harvesting on forest nutrient cycling. Literature reviews have also been completed for specific forest ecosystems (Patric and Smith, 1975, Weetman et al., 1979) a/ The general consensus of these reviewers is that conventional bolewood harvests of mid-age stands will

a/ Weetman, G. F., E. C. Clemmer, and D. Alger. 1979. Boreal forest nutrient balance after logging. Nutrient reserves and losses in a low site black spruce stand and a low site Jack pine stand. Preprint of a paper presented at the Symp. on Impact of Intensive Harvesting on Forest Nutrient Cycling. Syracuse, NY. 13-16 Aug. 1979.

have little impact on tree nutrition in future rotations. Atmospheric inputs of N and P occur in sufficient quantities to balance harvest removals. Soil reserves of K, Ca, and Mg are generally considered sufficient for numerous rotations even in the absence of any atmospheric or weathering inputs. Reports to the contrary (i.e. Cross and Grigal, 1980) have been based on mineral reserves of shallow soils determined by using weak extraction techniques.

Comparisons of nutrient removal in bolewood-only harvests versus nutrient removal in complete above-ground harvests are available for some commercially important forests. Weetman and Webber (1972) calculated that complete tree harvest of a 65 year old black spruce stand would remove 167, 42, 84, 27, and 277 kg/ha of N, P, K, Ca, and Mg, respectively. This amounted to a 300% increase of N and P and a 200% increase of K, Ca, and Mg removal above that which would be removed in a bolewood harvest to an 8 cm top. Similar increases have been reported for southern pine. Wells et al. (1975) reported that removals of P, K, Ca, and Mg would double for 16 year old loblolly pine (*Pinus taeda* L.) harvested using a complete above ground harvest in place of a merchantable bolewood harvest. Much larger removals would occur under intensive management schemes such as proposed by Koch (1980). Koch proposed a harvesting scheme for loblolly pine which would incorporate multiple thinnings into a 35 year rotation. At the end of the rotation crop trees would be harvested with their taproot and crown intact. Utilizing Koch's estimates of projected biomass removals, and available data on nutrient concentration of loblolly pine tissue, total nutrient removals under such a system can be calculated (Table 5). The 22, 3, 14, 16, and

Table 5 Estimated nutrient removals during a 35 year rotation of an intensively managed stand of loblolly pine of the future

Component	Harvested biomass[a]	Approximate nutrient concentration[b]					Nutrient removal				
		N	P	K	Ca	Mg	N	P	K	Ca	[illegible]
	-- kg/ha --	---------- % ----------					---- kg/ha ----				
Corridor thinning (age 4)											
Whole tree	24,000	.165	.020	.106	.120	.030	40	5	26	[illegible]	[illegible]
Intermediate thinnings											
Bolewood, bark, and taproot	170,700	.092	.012	.071	.090	.023	15[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tops, branches, and foliage	47,700	.455	.051	.244	.240	.054	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Crop trees											
Lateral roots	27,300	.176	.047	.168	.143	.060	48	1[illegible]	[illegible]	[illegible]	[illegible]
Bolewood, bark, and taproot	152,900	.092	.012	.071	.090	.023	141	18	103	138	[illegible]
Tops, branches, and foliage	32,900	.455	.051	.244	.240	.054	150	17	80	79	18
				Total removed			753	92	498	553	241

[a] Source: Koch (1980)

[b] Computed as a weighted average using the data of Wells and Jorgensen (1975), taproot concentrations were assumed to be equal to bolewood concentrations.

4 kg/ha of N, P, K, Ca, and Mg which would be removed on an annual basis are about 35% greater than removals in two 16 year rotations with complete above-ground harvest (Wells et al., 1975). These removal rates exceed bulk precipitation inputs by 300% (Table 2).

Accelerated Leaching and Erosion

Dissolved losses. Estimates of leaching losses following harvest and site preparation for a number of forest types and harvest conditions are presented in Table 6. Generally, increased nutrient export is limited to the first few years following harvest. The largest exports typically occur during the first post-harvest year and, as pointed out by Sopper (1975), are minor when considered over the length of a conventional rotation. Nitrogen losses, which occur primarily as NO_3, are most significant. Orthophosphate, which is also an anion, is readily complexed by soil organic matter and does not leach in significant quantities. Losses of other elements are small in comparison with nutrient reserves (Table 1). The large N losses following deforestation at Hubbard Brook reported by Likens et al. (1970) are the exception to this pattern. Their research should not be interpreted as a harvesting and site preparation study as no material was actually harvested and no vegetation, either planted or natural, was allowed to revegetate the treated watershed. Investigations of commercial clearcuts in the same area have reported much smaller N losses (Pierce et al., 1972).

In general, the soluble export of macronutrients increases with the degree of disturbance. Intensive site preparation which includes chopping, burning, and harrowing would be expected to maximize these losses from forest ecosystems, however, investigators working in the

Table 6 Soluble nutrient losses from harvested and site prepared areas during the first year following disturbance.

Forest type	Location	Disturbance	Total elemental loss and percent relative to control						
			NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg	
			kg ha^{-1} yr^{-1} (%)						
Douglas fir	Cedar River (Washington)	Clearcut	ND	0.5[a]	0.09(230)	0.2(6)	5.6(115)	ND	Cole and Gessel (1965)[b]
Douglas fir	H.J. Andrews (Oregon)	Clearcut/Slash Burn	0.2(2400)	1.5(5260)	0.55(207)	6.0(192)	81.4(368)	26.2(340)	Fredriksen (1970)
Northern hardwoods	Hubbard Brook (New Hampshire)	Clearcut	22.0(1100)	ND	ND	ND	27.0(270)	ND	Likens et al. (1970)[c]
Mixed hard woods	Parsons (West Virginia)	Clearcut	3.0(490)	1.5(104)	0.31(221)	5.0(139)	4.2(140)	3.4(139)	Aubertin and Patric (1974)
Mixed southern pine	B.F. Grant (Georgia)	Clearcut/Chop	0.5(191)	ND	1.09(170)	13.2(210)	12.5(106)	10.7(113)	Douglass (1975)[d]
Slash pine	Gainesville (Florida)	Clearcut/Chop/ H&P Pass	0.2(222)	1.0(295)	0.20(750)	ND	ND	ND	Hollis et al. (1978)
Slash pine	Bradford Forest (Florida)	Chop/Bed	0.1(0)	0.1(0)	0.02(50)	0.2(432)	0.4(0)	0.8(33)	Riekerk (1981)
Slash pine	Bradford Forest (Florida)	Chop/Burn/KG-blade/Harrow/Bed	0.1(0)	0.1(0)	0.01(0)	0.2(210)	0.5(11)	0.4(0)	Riekerk (1981)

[a]Total N

[b]Estimated annual values based upon 10 month data

[c]Mean [illegible] watersheds

[d]Estimated from graphical presentation [illegible]

Coastal Plain where these practices are most common have not reported large losses following these activities. Hollis et al. (1978) reported that NO_3-N, NH_4-N, and PO_4-P exports from a harvested, chopped, and N plus P fertilized watershed in the wet savannah of Florida were only 0.1, 1.6, and .04 kg/ha greater, respectively, than from an undisturbed control (Table 6). The results of a study concerning the impact of two intensities of harvest and site preparation on nutrient exports from a flatwoods forest have been reported by Riekerk (1981). He failed to detect significant differences in the exports of NH_4-N, NO_3-N, PO_4-P, and Mg in runoff from watersheds which were undisturbed, clearcut harvested, chopped, and bedded, and clearcut, chopped, burned, windrowed, harrowed, and bedded. The exports of K and Ca from the more intensively prepared watershed were greater than the exports from either the less intensively prepared or undisturbed watershed during the treatment year but, these differences could not be detected during the first post-treatment year (Table 6).

Sediment losses. Modest increases in soil erosion occur following harvest and site preparation. These increases are generally of short duration and are small when evaluated in the context of conventional rotations throughout the eastern United States (Patric, 1976), large losses are generally limited to mountainous area of the west (Fredriksen, 1970a).

Felling trees does not, in itself, increase erosion. Most harvesting related erosion results from road construction (Stone, 1973, Anderson et al., 1976). Fredriksen (1970a) reported that sediment

yield from a small watershed in western Oregon which was harvested using a skyline system and did not require road construction, was only three times greater than from an undisturbed control watershed during the first post-harvest year. The sediment yield from a conventionally harvested watershed, which required road construction, was 100 times greater than that from the undisturbed control.

The impacts of forest management activities on sediment production in the Southeast have been recently reviewed by Yoho (1980) whose summary is presented in Table 7. The sediment yields from undisturbed forests and pine plantations are low, ranging from trace quantities to a maximum of 0.7 metric tons ha/yr. Sediment losses from watersheds which have been periodically burned, thinned, or carefully clearcut are within this range, however, large increases in sediment production were associated with careless clearcuts and site preparation.

The effect of different site preparation methods on sediment production has been investigated on steep slopes in the upper Coastal Plain (Beasley, 1979). Only small differences in sediment losses between chopped, sheared and windrowed; and sheared, windrowed, and bedded sites occurred. First year sediment yields from these sites were 12, 13, and 14 metric tons/ha, respectively. Sediment yield from the control watershed was 0.6 metric tons/ha during the same period. Sediment yields following comparable intensities of site preparation in flatwoods landscapes of the lower Coastal Plain were much lower than these values. Riekerk (1981) reported that the sediment yield from a clearcut, chopped, burned, windrowed, harrowed, and bedded watershed was less than 0.2 metric tons/ha during the treatment year.

Table 7. Sediment losses from managed watersheds in the southern pine region during the first post-treatment year a/

Management activity	Range of sediment yields reported
	– metric tons ha^{-1} yr^{-1} –
Undisturbed natural forests	trace – 0.72
Pine plantations	trace – 0.18
Forest thinning	trace – 0.13
Periodic burning	0.02 – 0.52
Annual burning	0.74 – 17.74
Careful clearcut	0.13 – 0.38
Careless clearcut	3.02
Mechanical site preparation	12.5 – 14.2

a/ Source: Yoho (1980).

Estimates of sediment associated nutrient loss following harvest and site preparation are not available for the southern pine region. Although Beasley did not report nutrient losses associated with accelerated sediment export, they can be estimated using assumed concentrations. Assuming N and P concentrations of 0.05% and 100 ppm, the losses of these elements from the most intensively prepared site during the first post-treatment year were 7.1 and 1.4 kg/ha, respectively. These losses decreased to 2.7 kg/ha N and 0.6 kg/ha P during the second year.

Volatilization and Denitrification

Volatile losses of N during site preparation burns can be large. Pritchett and Wells (1978) estimated N losses to be between 200-300 kg/ha for complete burns on southern pine sites. Increases in soil pH and nutrient availability and better post-harvest soil conditions could, in theory, also stimulate N losses through denitrification. Any such increases are, apparently, offset by the accelerated rates of N fixation which have been reported followed fire (Jorgensen and Wells, 1971). Gaseous losses of S and particulate export of P, K, Ca, and Mg in flyash also occur (Lewis, 1974) but the magnitudes of these losses have not been quantified.

Nutrient Displacement

The movement of harvest slash, residual vegetation, and soil into windrows by tractor-mounted rakes and blades has been estimated to displace up to 1400 kg/ha N in pumice soils of New Zealand (Webber, 1978). Although this material is not actually removed from the site,

it is, nevertheless, not available to most of the new plantation. Although windrowing is accepted as a potential source of site productivity decline in the southern pine region (Haines et al , 1975, Pritchett and Wells, 1978; Williston, 1980) few estimates of the nutrient content of windrows exist. Burger (1979) estimated that the total N reserves of a windrowed site in central Florida were 479 kg/ha less than on an adjacent site which was chopped-only. Phosphorus and K reserves were 13 and 23 kg/ha lower on the windrowed site. Similar estimates have been reported by Ballla et al, (1978) and Pritchett and Wells (1978). Other mechanisms of large scale nutrient translocation, such as associated with yarding areas or delimbing gates, also exist but are less systematic and, consequently, less important for determining the nutrient status of the site. Nutrients are systematically transplaced during the bedding operation (Haines and Pritchett, 1965, Shultz, 1976) but the distances the materials are moved are small and, thus, do not result in a net removal of nutrients from the planting surface.

Nutrient Mineralization Following Harvest and Site Preparation

General

The principal effects of harvesting and intensive site preparation treatments used to regenerate southern pine occur at the soil surface. Changes in factors which govern the activity of heterotrophic organisms are reflected in mineralization rates. The interaction of mineralized nutrients with biotic and abiotic immobilization processes and soil water dynamics largely determines the quality of water, and dissolved

nutrient export from harvested watersheds. Despite the widespread use of intensive site preparation, and the generally acknowledged benefits these techniques have on seedling nutrition (Haines et al., 1975, Pritchett and Wells, 1978), relatively little information is available on the mechanisms through which they influence mineralization processes.

Mineralization Dynamics

Nutrient mineralization is a biologically mediated process which is controlled by those factors which alter the species composition, growth, or activity of microbial populations. Excellent reviews of microbial ecology, which discuss the various chemical, physical, and biological factors which affect population dynamics, are available (Stolzy and Van Gundy, 1968, Stotzky, 1972, Dickinson, 1974). These factors include substrate availability, C/N ratio, growth hormones, inorganic nutrients, temperature, moisture, solar radiation, pH, oxidation-reduction potential, and microbial interactions. As Stotzky points out, a change in one of these factors affects the others. For instance, a change from saturated to unsaturated conditions will cause direct changes in the soil atmosphere, pH, oxidation-reduction potential, and thermal characteristics. Despite the complexity of these interactions, reasonable relationships between mineralization rates and the most important physical factors have been developed.

Moisture. Periodic drying and rewetting has been recognized as increasing nutrient availability, particularly of N, for many years (e.g. Lebedjantzev, 1924). Recent investigations have demonstrated that this occurs coincident with an explosion of microbial activity

stimulated by amino acid release (Birch, 1960) and the decomposition of microbes killed during the drying process (Lund and Gökæver, 1980). Phosphorus availability may be greater during, or immediately following, saturated conditions due to chemical processes in which complexed P is solubilized as ferric iron is converted to the ferrous iron form (Mulder et al., 1969).

Attempts to quantify mineralization rates at different soil moisture levels have not produced consistent results. The use of soil water content, or soil water content adjusted for water holding capacity, has contributed to the problems associated with interpreting the relationships between soil water and microbial activity. In recent years there has been a shift away from the use of these traditional measures of soil moisture and toward use of more direct measures of soil water potential.

Under stable conditions decomposition and mineralization occurs most rapidly at soil water potentials approximately equal to field capacity (-0.1 to -0.3 bars). At lower potentials these processes decrease in two distinct phases. A rapid decrease occurs at potentials between -0.3 and -10.0 bars. This decrease has been related to the logarithm of the water potential by a number of investigators (Bhaumik and Clark, 1947; Miller and Johnson, 1964; Singh et al., 1969). Sommers et al. (1981) pooled the data from these and other investigators and developed generalized equations for predicting decomposition[a] and N mineralization rates at a constant temperature as the

[a] Based on CO_2 evolution.

range of water potential. The equation for N mineralization, (Eq. [11]) was based on the data of Stanford and Epstein (1974) and described the relationship of N mineralization rate (k) at any water potential (Ψ) between 1.0 and -2.0 bars to N mineralization at optimal moisture conditions (k_{max})

$$k/k_{max} = 0.325 (\log - \Psi) + 0.744 \qquad [11]$$

Mineralization rates decrease only slowly at water potentials less than -10.0 bars and the rate of decrease is directly proportional to the decrease in soil water potential (Sommers et al., 1981). Mineralization rates decrease sharply as water potentials increase from field capacity to saturation and drop to less than 40% of their maximum at saturation (Sindhu and Cornfield, 1967; McKay and Carefoot, 1981).

Temperature. Each step in the mineralization process is catalyzed by temperature sensitive enzymes produced by organisms whose growth is conditioned by temperature (Alexander, 1961). The effects of temperature will vary depending on the nutrient and chemical form of the nutrient being analyzed. Most heterotrophs are mesophiles with an optimum temperature between 25° to 35°C (Dickinson, 1974). Early experimentation demonstrated a general increase in organic matter decomposition (Waksman and Gerretsen, 1931, Merk, 1938) and nitrification rates (Panganiban, 1925, Russell et al., 1925) with temperature increases in the 5° to 35° centigrade range. More recently, these increases have been quantified. Stanford et al. (1973) analyzed the affect of temperature regimes of 5°, 15°, and 25°C on N mineralization from homogenized cores of 11 soil types. They concluded that the mineralization rate increased exponentially with temperature and

approximately doubled for each $10^{o}C$ rise in temperature (Q_{10} = 2.1). Similar Q_{10} values for N mineralization have been reported by other researchers (Powers, 1980, Hsieh et al., 1981)

The bacteria responsible for ammonification are, in contrast to most heterotrophs, thermophilic. Optimal temperatures for these organisms are between 40^{o} and $60^{o}C$. At these temperatures, nitrification is slow and increases in NH_4-N concentrations, such as reported by Justice and Smith (1962), may occur. Cold temperatures (less than $7^{o}C$) also favor build-ups of NH_4 in the soil as a result of almost complete suppression of nitrification (Harmsen and Kolenbrander, 1965)

Phosphorus mineralization processes have received less attention than N mineralization. Like ammonification, phosphorus mineralization is favored by temperatures in the thermophilic range and is slow below $30^{o}C$ (Thompson and Black, 1947). Thermodynamically controlled immobilization processes also occur at more rapid rates at higher temperatures, thus, measured phosphorus release may not parallel actual mineralization.

Studies of the interactive nature of temperature and moisture effects are limited. In the aforementioned study, Justice and Smith (1962) investigated the mineralization of organic N to NH_4-N, NO_3-N, and NO_2-N under 9 temperature-moisture regimes. They were unable to demonstrate differences between mineralization rates due to these factors. A more recent study by Cassman and Munns (1980) does, however, provide evidence for a temperature and moisture interaction. These investigators incubated soils at 4 temperatures and 6 moistures in a factorial combination. Nitrogen mineralization rates at high

temperatures and low moistures were increased slightly above the [illegible] predicted by a purely additive model

Disturbance. Few quantitative studies have been conducted to examine the effects of physical changes associated with disturbance on mineralization rates. Most laboratory studies have utilised homogenized tissue and/or soil samples without an undisturbed control. Results published by Kaunisto and Norlamo (1976) are a notable exception. In their study of peat soils they demonstrated that rotavation increased NH_4-N and NO_3-N mineralization approximately 50% when compared with an undisturbed control. The impact of rotavation was greater at higher temperatures. Results similar to these have also been reported following mixing of coniferous humus (Salonius, 1978).

Soil characteristics. Development of a useful method for predicting the mineralization potential of different soils has proven difficult. Nitrogen mineralization has received the most attention. Correlations between total soil N and N mineralization across soil types are poor (Harmsen and van Schreven, 1955). Organic materials from different sources, and in different states of degradation, are not equally susceptible to decomposition (Mikola, 1954; Waight, 1965; Overrein, 1972). These organic substrates, as well as physical, chemical, and biological properties which affect decomposition, vary between soils. Thus, it is not surprising that correlations between soil types, or with measures of total N content, are poor. Most recent work has attempted to circumvent this problem by utilizing N availability indexes determined by incubation. These techniques, and their application to forest ecosystems, have been recently reviewed by Keeney (1980).

Excellent correlations between N mineralization observed under controlled conditions and in situ mineralization have been reported for agricultural soils (Stanford and Smith, 1972, Smith et al , 1977, Herlihy, 1979). The utility of these techniques for estimating mineralization from forest soils has not been sufficiently investigated, but the initial results appear promising. Van Pragg and Weissen (1973) successfully correlated N released on incubation to measured release from forest floor materials developed under spruce but were unable to associate this with growth responses. Powers (1980) was able to correlate measures of N availability, which were determined on the basis of anaerobic incubations, both with the quantities of N mineralized in the field and with the growth and foliar N concentrations of ponderosa pine (P. ponderosa Laws.)

Relationships Between Microclimatic Changes and Mineralization Following Harvest and Site Preparation

Soil temperature and moisture. Removal of the forest canopy and disturbance of the forest floor upsets the relatively stable microclimatic conditions which existed beneath the litter layer prior to harvest. Surface soil temperature maxima are increased, and minima decreased, by a magnitude which depends upon soil characteristics, moisture relationships, and the degree to which the surface is exposed to direct sunlight. Reported differences in the maximum temperature near the soil surface following harvest and site preparation range from almost zero in peat soils (Brown, 1976) to more than 20°C at 2-5 cm depth in sandy soils (Shultz, 1976). Research on flatwoods soils of the lower Coastal Plain has demonstrated that maximum soil temperatures

increase with increasing intensities of site preparation. In the aforementioned study, Shultz reported that the average June maxima at 2.5 cm depth were 38°, 42°, and 51°C on clearcut sites which were prepared by burning, burning and double disking, and burning, double disking, and bedding, respectively. The comparable maximum temperature in an undisturbed forest was 28°C. Similar results for a flatwoods site have been cited by Swinger (1979).

Soil moisture increases are also associated with canopy removal. On upland sites this is expressed by increased watershed runoff (Hibbert, 1967; Stone et al., 1979) while on poorly drained sites it is evidenced by rises in the water table (Trousdell and Hoover, 1955; Hollis et al., 1978).

Overall moisture increases or water table rises may not be very closely related to mineralization processes at the soil surface. In sandy soils, rapid evaporation from the soil surface can dry out the uppermost horizon which then acts as a barrier to upward movement from the water table due to its low unsaturated hydraulic conductivity (Overman and Zakariah, 1975). Thus, drier surface soil conditions may occur on harvested sites even though a water table rise is reported.

Correlations with field investigations. Few attempts to quantify in situ mineralization rates with measured changes in microclimatic conditions have been reported for forest ecosystems. Changes in mineralization rates have, however, been indexed following harvesting (Cole and Gessel, 1965; McColl, 1978), fire (Grier and Cole, 1971; Lewis, 1974) and site preparation activities (Swinger, 1978; Pritchett,

1981) by monitoring changes in soil solution chemistry. These studies have generally lacked the data necessary to correlate the observed changes with differences in moisture, temperature or other factors.

Pritchett (1981) monitored changes in soil solution chemistry following two intensities of harvest and site preparation in a Coastal Plain flatwoods. He found that NH_4-N, NO_3-N, P and K concentrations were increased for a six month period following harvest and site preparation. Measured NH_4-N concentrations were highest in intensively prepared sites (windrowed and bedded) and reached a peak of 3 ppm. This corresponded to a 30-fold increase above concentrations measured in solution from the undisturbed control. These peaks occurred following dry periods. Peak NO_3-N concentrations were observed 3 months after the NH_4-N peaks and were also correlated with dry periods. In a study similar to Pritchett's, Burger (1979) reported that NH_4-N, NO_3-N, P, and K concentrations were significantly higher in soil solutions from an intensively prepared site (windrowed, disked, and bedded) than from an undisturbed control. A similar increase was not observed in an adjacent site that was prepared by chopping. Burning significantly increased nutrient concentrations in all but the winter season.

McColl published the results of a unique investigation of in situ mineralization from the forest floor and soil under a Douglas-fir stand in 1973. He found that total ion concentrations of leachate varied with 3 environmental factors: (1) the duration of the dry period prior to leaching, (2) the dry period temperature, and (3) the amount of leachate collected.

MATERIALS AND METHODS

Study Area Description

General

Slash pine, or mixed slash pine-longleaf pine (*Pinus palustris* Mill.) ecosystems, occupy 5.2 million ha of land[a] extending in a broad band from eastern Texas through Florida and into the coastal regions of North Carolina (Sheffield et al., 1981, mimeo report). "Flatwoods" are a major landscape within this resource base. They are characterized by low relief and poorly defined first-order streams. Cypress ponds and swamps comprise 25-30% of the landscape (McCulley, 1950). The soils are, predominately, poorly to very poorly drained although local areas of well drained soils occur.

The research area was located on a flatwoods landscape in north-central Florida (Fig. 1). Field investigations were conducted on three experimental watersheds of 64, 48, and 137 ha. An attempt had been made to isolate each watershed by a series of road-ditches. Nutrient imports and exports were being monitored for all three watersheds in

[a] Naturally regenerated or planted stands in which yellow pines constitute 30% or more of the stocking volume and in which slash pine is the dominant pine.

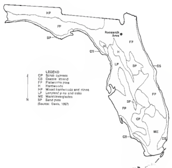

Fig. 1 - Location of the study area

conjunction with the IMPAC[2/] program at the University of Florida (Riekerk et al., 1979). Elevation varied less than 2 m over the entire 249 ha research area, ranging from 43 to 45 m above mean sea level. Surface waters drained southward through a series of cypress ponds and old drainage ditches into an extensive swamp. The mean annual temperature was 21°C, ranging from a mean monthly low of 14.4°C in January to a mean monthly high of 27.3°C in July. Annual precipitation averaged 133 cm, the bulk of which occurred in the wet winter and summer months (Climatological Data, Gainesville). Winter precipitation was primarily of frontal origin while summer precipitation was usually of convectional origin.

Soils

Five soil series and one series variant were described on the research area (Appendix A). Moderately well drained soils of the Ocilla series (Arenic Paleudult) were characteristic of the driest areas and occurred over 12% of the research area (Fig. 2). Poorly drained soils of the Mascotte series (Ultic Haplaquod) occurred over 38% of the area. Spodosols such as this are characteristic of flatwoods landscapes. They have a fluctuating water table which occurs to within 25 cm of the soil surface for 1 to 4 months of the year and occurs at depths of less than 100 cm for up to 6 months of the year. Permeability and root penetration are restricted by the presence of a B2h horizon which occurs at 30-50 cm depth. The third major soil series

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[2/] Intensive Management Practices Assessment Center, Univ. Florida, School of For. Resour. and Conserv., Gainesville 32611.

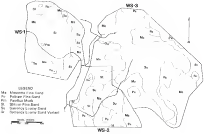

Fig. 2 — Soil type map of the research area.

described was the Surrency series (Arenic Umbric Paleaquult) which occurred over 39% of the research area. These soils are very poorly drained. The water table is within 25 cm of the soil surface for more than 6 months of the year, and water stands on the surface for up to 4 months annually. Most Surrency soils mapped in Watershed 1 were mapped as a variant. They differed from the modal type in both depth to the B2t horizon (deeper) and color (lighter hue). Two other soils, a Terric Medesaprist (Pamlico series) and a Arenic Paleaquult (Pelham series) were also mapped. These soils occurred over less than 11% of the research area.

A B2t horizon of low permeability occurred in all soils mapped on the research area. Typically, this horizon occurred at depths of 1 m or less, however, it was not uncommon for the B2t horizon to occur at depths of up to 2 m in the Surrency variant. Rooting was restricted by this horizon.

Vegetation

The vegetation was characteristic of naturally regenerated pine flatwoods. The three distinct forest types mapped (Fig. 3) were pine flatwoods proper, ponds and bayheads, and pond margins (Swindel et al., 1981). Table 8 lists plant species associated with each of these vegetation types.

The vegetation types roughly corresponded to soil mapping units. Vegetation mapped as flatwoods generally occurred on Stilson and Mascotte soils. Pond and pond margin vegetation coincided with soils mapped as the Surrency, Pelham, or Pamlico Series. Preliminary cruise data

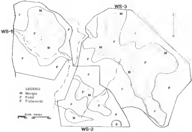

Fig. 3 Vegetation type map of the research area

frequently encountered plants in vegetation types of turbed forest stands [a]

Form	Flatwoods	Margins	Ponds
Trees	Pinus elliottii	Pinus elliottii Taxodium distichum	Taxodium distichum Pinus elliottii Nyssa sylvatica
Shrubs	Ilex glabra Vaccinium spp Myrica cerifera Serenoa repens	Lyonia lucida Myrica cerifera Smilax spp Ilex glabra	Lyonia lucida Myrica cerifera Smilax spp Ilex myrtifolia

[a] Source: Swindel et al (1981)

indicated that changes in tree biomass also coincided with changes in soil type. Overstory biomass was greatest on Stilson soils whereas shrub biomass was greatest on Surrency soils.

Field Investigations

Installation of Permanent Plots

Paired soil and vegetation monitoring plots were established within each of the 3 major soils types (Mascotte, Stilson, and Surrency series) which were mapped on the research area (Fig. 4). A total of 27 plot pairs (3 watersheds x 3 soil types x 3 replications) were permanently marked and tied into a survey grid which had been established for the research area. Each 10 x 10 m monitoring plot was separated from the adjacent member of the plot pair by a 20 m wide buffer strip. A 5 m wide perimeter around the 10 x 10 m soil monitoring plot was reserved for soil and litter sampling.

Pre-Harvest Nutrient Distribution

Soil and forest floor. The distribution of nutrients in the organic and mineral soil horizons were determined on each permanent plot prior to any management activities. Samples from the O1 and O2 horizons were collected from within a 0.1 m^2 steel frame, bagged, labeled, and returned to the laboratory where they were dried at 65°C and weighed. The entire sample was ground to pass a 2 mm screen in a Wiley mill and subsampled for chemical analyses. Three replicate samples were collected on each plot.

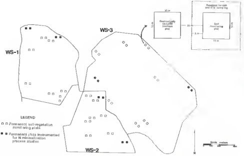

Fig. 4 - Sample plot locations.

Soil samples were collected from each mineral horizon down to, and including, the surface 25 cm of the B_{2t} horizon (approximately 1 m). Three replicate samples of the A1, A2, and B2h (where present) horizon were collected from the reserved area around each permanent soil monitoring plot. Each replicate was a composite of 15 2.5 cm diameter cores. Average horizon thickness and depth were recorded for each replicate sample. Samples were air-dried before analyses.

Above ground vegetation. A related study determined nutrient distribution in standing vegetation by destructive sampling of the biomass plots (Swindel et al., in press). Data from these plots were used to develop relationships between d.b.h. and component weight for all overstory vegetation (Conde et al., 1979). The average weight of the overstory components on each soil type were determined from these relationships using the results of a 1% tally cruise. Understory weights were determined directly from sample plot weights and converted to a kg/ha basis.

Harvest and Site Preparation Treatments

After a 1 year survey and calibration period, the watersheds were site prepared and planted according to the schedule presented in Table 9.

The low intensity treatments imposed on watershed 1 were designed to minimize soil exposure, residue displacement, and fossil fuel consumption while still permitting machine planting. Trees were felled by two-man logging crews using chain saws. The stems were delimbed,

Table 9 Schedule of harvesting and site preparation activities on the experimental watersheds

	Date(s)	Low intensity site preparation (WS-1)	High intensity site preparation (WS-2)	Control (WS-3)
1978	Nov.-Dec	Harvest (short wood)	Harvest (long wood)	
1979	Jan.-Feb		Lighter-wood stump removal	
	Apr	Chop		
	May		Burn	
	June		Windrow (KG-Blade)	
	Aug	Chop	Harrow	
	Sep.-Oct.	Bed	Bed	
	Nov	Plant	Plant	

bucked to 1.2 m lengths, and hand stacked on pallets for removal on flatbed trucks. Residual vegetation and slash was broken up by chopping with a Fleco drum chopper. Beds were formed by a single pass of a Rome bedding plow. Adjacent beds were about 3.5 m apart (measured from crown to crown). The area was machine planted in November after the beds had settled for approximately two months. Seedlings were planted approximately 1.5 m apart.

The high intensity harvest and site preparation was a combination of the most intensive treatments utilized by forest industry in the Southeast. The treatment sequence involved more, larger, and faster equipment which required more fuel and generated increased site disturbance. Trees were cut by a feller-buncher and moved full length to the yarding area by rubber-tired skidders. Lateral branches were removed in a delimbing gate prior to loading. This created five large slash piles per 10 hectares of harvested area. Resin loaded stumps persisting from the previous forest crop (lighter wood) were removed for destructive distillation immediately after harvest. Residual slash and litter was chopped, and everything except the unharvested ponds, burned and windrowed the following spring. Windrowing operations were completed by an experienced operator under commercial conditions using a shearing KG-blade mounted on a D-6 Caterpillar tractor. The area between the windrows was then harrowed, bedded, and planted. Bedding and planting operations were similar to those of the low intensity site preparation.

Post-Harvest Nutrient Distribution

Litter and residual slash. The quantities of nutrients remaining

in the organic horizons, residual logging slash, and surface soil of the interwindrow area (the planted surface) were determined by resampling the permanent soil monitoring plots. Five replicate samples of litter and slash were collected from both the bedded and interbedded areas of Mascotte and Stilson soils on each of the harvested watersheds. Samples were obtained by removing all organic surface materials from within a 0.1 m^2 steel frame. Slash materials which had been incorporated into the surface soil during site preparation were separated from the mineral soil by excavating all material within the 0.1 m^2 frame to the base of the surface horizon (Fig. 5) and sieving it through a 1 cm screen. Non-sievable woody materials were included with the litter and slash sample. Each replicate sample, which was a composite of two 0.1 m^2 samples, was returned to the laboratory where it was dried at 65°C and weighed. The sample was ground in a Wiley mill and the ground material was subsampled and stored for subsequent chemical analyses.

<u>Soil</u>. Soil samples were collected in January of 1981, approximately 5 months after the litter samples were collected and approximately 14 months after the area was planted. Ten sets of trenches were excavated across the beds and adjacent interbed areas to the base of the surface horizon. The total width of the bed, interbed area, and separating gully were measured. Measurements of surface soil depth were made at the crown of the bed and at intervals across the bed and interbed areas. One 4.4 cm diameter core was obtained from the undisturbed soil adjacent to each trench. Each core was driven to the base of the surface horizon, removed, and its entire contents emptied into a sample bag on which the depth of the core was recorded. Soil cores were also obtained from

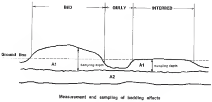

Fig 5 - System for sampling soil and residual slash following harvest and site preparation

Stilson and Tascotte soils in the control watershed in a similar fashion.

On returning to the laboratory, each soil core was air-dried and weighed. Subsamples from each core were removed for oven-dry weight conversion. Bulk densities were calculated for each of the 20 cores using volumes computed from the recorded information on core depth. Two of the ten air-dried samples were combined to yield five composite samples for chemical analyses.

Windrow sampling

The nutrient contents of the organic and mineral components of the windrows were determined in August 1979. Each windrow was numbered and its length measured. Cross-sectional areas were determined at 50 m intervals along the windrow from a randomly selected starting point on each windrow. Height measurements used to compute cross-sectional area were made at 0.25 m intervals across the windrow ignoring isolated branch and bolewood pieces which protruded from the windrow. Cross-sectional areas were computed by summing the areas of individual trapezoids defined by the measurements.

Ten cross sections, which were to be excavated, were randomly selected from the 107 measured cross sections. At each selected location, all material from within a 1-m wide cross section was removed and separated into the following three components:

1. Coarse wood - woody material > 2.5 cm diameter.
2. Fine branch plus root wood - woody material between 1.3 and 2.5 cm diameter and not passing a 1.3 cm screen.
3. Soil-soil, litter, and woody material which passed a 1.3 cm screen.

The coarse wood and the bulk of the fine branch plus root wood components were separated by hand. The soil was sieved through a 1 cm screen and the retained residues included within the fine branch and root wood component.

All material was weighed at ambient moisture in the field. Three random subsamples of each component were collected, immediately weighed, and returned to the laboratory for dry weight determination (65°C) and nutrient analyses.

Soil Solution Monitoring

Soil solution was sampled on a regular basis during a three year period which began at the start of the calibration year and ended one year after site preparation and planting were completed. One set of ceramic cup samplers, such as described by Wagner (1962), was installed at the base of each soil horizon in each of the 27 permanent monitoring plots. Following site preparation, an additional tube was installed at the base of the A1 horizon over which a bed had been formed. As suggested by Wood (1973), all cups were prelesched with dilute hydrochloric acid followed by deionized distilled water prior to installation in the field. Holes, which were the same diameter as the soil solution sampling tubes, were augered to the desired depth and the solution sampling tubes set firmly in place. Three sets of samples were collected and discarded prior to the initiation of regular sampling.

Solution samples were collected on a monthly basis except during the spring of 1979 and 1980 when the concentrations of dissolved ions were expected to be high as a result of harvest and site preparation activities. Samples were collected on a weekly basis during these periods. Two days were required to complete the sampling. On the first day all

residual solution was pumped from the sampling tube and a vacuum of 70 to 80 centibars applied with a hand pump. The samplers were allowed to collect solution overnight. Samples were collected the following day and immediately placed on an ice-filled chest until returned to the laboratory 4 to 6 hours later.

Some of the site preparation treatments imposed on the watersheds necessitated temporarily removing the solution samplers. Whenever possible, the auger hole from which the samples had been removed was sleeved with a section of PVC pipe, thus allowing the samplers to be replaced in the same hole. In instances where this was not possible, such as following windrowing operations, solution samplers were reinstalled as near as possible to their original locations.

Nitrogen Mineralization Process Study

Two of the permanent monitoring plots, one Mascotte and one Sellers, were selected for intensive studies of N mineralization processes in each watershed. Each plot was instrumented with a series of tensiometers with mercury manometers, recording and maximum/minimum reading thermometers, and micro-lysimeters. Tensiometer cups were installed at 5, 15, 35, 55, and 85 cm depths in both the bed and inter bed areas of the plot. Three replicates of the 5 and 15 cm depths were installed, but the deeper depths were unreplicated. Recording thermometers were installed at 10 cm depth in both the bed and interbed areas of the plot by inserting the probe into the side of a narrow trench beneath the undisturbed surface. Probe leads were buried about 10 cm deep for a distance of 2 m behind the probe as a means of shielding the probe from conductive heat transfers with the soil surface. Two

maximum/minimum reading thermometers were also installed at 0.2 cm and 1 cm depth in the bed and interbed areas. They were shielded from direct sunlight by placing them in a short section of partially buried PVC pipe through which they could be accessed.

Three microlysimeters were constructed in both the bed and interbed areas of each plot using 15.3 cm diameter PVC pipe and 15 cm diameter tension plate lysimeters as described by Cole (1968). The installation procedure was designed to minimize soil disturbance. A 22 cm long section of PVC pipe, which had been sharpened at one end, was inserted into the soil so that its top edge was flush with the ground surface. A hole was excavated along one side of the pipe and the soil removed from the bottom 2 cm. A lysimeter plate was inserted into the base of the pipe and soil packed firmly under it. The access tube was then led into an air-tight polypropylene sample bottle and the hole refilled. The sample bottle was connected to an elevated water reservoir. Tension was placed on the lysimeter plate by starting a flow between the elevated reservoir and a storage reservoir placed on the ground (Fig. 6). Water was siphoned from the elevated reservoir until the partial vacuum in the system was equivalent to the difference in hydraulic head between the siphon and collection reservoirs. Soil water held at tensions which were equivalent, or less than, the established partial vacuum were drawn into the ceramic plate displacing an equal volume of water from the elevated siphon reservoir. The partial vacuum placed on the system was adjusted to approximate the measured soil water tensions at 35 cm depth by raising and lowering the siphon reservoir.

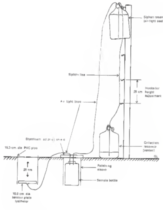

Fig. 6 - Construction details of microlysimeters

Manometer and maximum/minimum thermometer readings were made on a daily basis from May to early November of the first growing season. Leachate was collected from the lysimeters following each rainfall event. Samples were kept cool during the trip to the laboratory where they were weighed and subsampled for chemical analyses.

Laboratory Analyses

Plant Tissue and Litter

Nitrogen and P concentrations of above-ground vegetation were determined colorimetrically following block digestion (Technicon Industrial Systems, 1978). Nitrogen concentrations of the litter and slash were determined by macro-Kjeldahl (Bremner, 1965) and P concentrations following dry ashing by the ascorbic acid-antimony procedure (Murphy and Riley, 1962). The concentrations of K, Ca, and Mg were determined on ashed samples of both plant tissue and litter by atomic absorption.

Soil

Organic matter contents of all soil samples were determined by the Walkley-Black wet oxidation technique (Jackson, 1958) and total N by macro-Kjeldahl (Bremner, 1965). Soil samples were extracted with 0.05 *N* HCl/0.25 *N* H_2SO_4 (Page et al., 1965) and P, K, Ca, and Mg determined on the extracts by atomic absorption spectrophotometry. Phosphorus, K, Ca, and Mg concentrations of windrow soil were also determined after dry-ashing.

Mineralizable N was determined for post harvest soil samples by the aerobic incubation procedure described by Stanford et al. (1974) with minor modifications. Five replicate soil samples were obtained

from each plot which had been instrumented for the mineralization process studies. Each replicate was a composite of ten individual 2.5 cm diameter cores taken to 20 cm depth (the same depth at which lysimeters had been installed). The soil samples were air-dried and sieved through a 2 mm screen.

A forty gram subsample of the air-dried soil was mixed with 7 g of exfoliated vermiculite which had been ground to pass a 2 mm screen. The sample was placed in a leaching tube constructed from 4.4 cm PVC pipe which had been fitted with a rubber stopper, filtering disk, and glass wool plug at one end. Parafilm was placed over the rubber stopper to prevent volatile carbon disulfide from entering the leaching tube during incubation. This substance is a decomposition product of rubber stoppers and has been reported to inhibit nitrification in low concentrations (Powlson and Jenkinson, 1971).

The samples were leached with 150 ml of 0.01 *N* $CaCl_2$ followed by 25 ml of a minus-N nutrient solution (0.002 *M* $CaSO_4 \cdot 2H_2O$, 0.002 *M* $MgSO_4$, 0.005 *M* $Ca(H_2PO_4)_2 \cdot H_2O$, and 0.0025 *M* K_2SO_4) prior to the initial incubation and at intermediate leachings. Excess water was removed to approximate field capacity by applying a 0.1 bar partial vacuum. The tubes were incubated at 35°C in a 95% RH atmosphere for cumulative periods of 7, 21, 35, 62, and 93 days. Leachates obtained at the end of each incubation were measured and analyzed for NO_3-N and NH_4-N concentrations.

Soil Solution and Leachate

Soil solution and leachate samples were analyzed for pH, conductivity, NH_4-N, NO_3-N[a], total N (Kjeldahl), PO_4-P, and total P concentrations. The pH was determined using a glass electrode pH meter. Conductivity was measured with a standardized carbon-graphite cell. Inorganic forms of N and P were determined colorimetrically (Technicon Industrial Systems, 1973, 1975, 1977) and total determinations were usually completed within 96 hours of sample collection. N and total P were determined colorimetrically (Technicon Industrial Systems, 1978) following digestion in 2.4 N H_2SO_4 (Technicon Industrial Systems, 1975).

Statistical Analyses

Treatment Comparisons

Data from the 18 permanent monitoring plots on Stilson and Mascotte soils (which were harvested and site prepared) were analyzed as a fully replicated factorial design (2 soils x 3 treatments). A required assumption was that systematic variations between watersheds were small in comparison to the natural variability within soils mapped as the same series. This assumption appeared reasonable in light of the large distances that separated the sample plots but was also tested during the calibration year. Data from the nine plots on Surrency soils were analyzed separately as these plots were not harvested and site prepared.

Analyses of the treatment effects were conducted using general linear model procedures (Barr et al., 1979). Significant differences

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[a] Includes NO_2-N

between treatment means were tested using single degree of freedom contrasts which addressed the following hypotheses where T represented the treated watersheds and C represented the unharvested control

Ho: The overall effect due to the treatments was not significantly different from 0

Contrast: $1(\bar{T1}) + 1(\bar{T2}) - 2(\bar{C}) = 0$

Ho: The effect of the low intensity site treatment was not significantly different from the effect of the high intensity treatment

Contrast: $1(\bar{T1}) - 1(\bar{T2}) + 0(\bar{C}) = 0$

The effect of bedding was evaluated separately as a split plot within the main plot treatments (watershed x soil combinations) of the two treatment watersheds

Windrow Composition

Statistical Analysis System (SAS) programs (Barr et al ,1979) were used to fit linear and polynomial regressions of compost weight (y) on cross-sectional area (x) Three regression models were fitted, a linear-zero intercept model (Eq [2]), a linear model with an estimated intercept (Eq [3]), and a quadratic-zero intercept model (Eq [4])

$$y = mx \quad [2]$$

$$y = mx + b \quad [3]$$

$$y = mx^2 + nx \quad [4]$$

Mineralizable Nitrogen (No)

The contents of mineralizable nitrogen (No) were estimated according to the procedures of Stanford and Smith (1972). The 'best' estimates of No (Eq. [5]) were obtained by changing initial estimates of No by small increments until the r^2 values for the regressions of cumulative N mineralization (Nt) over time (t) were maximized.

$$\ln (No - Nt) = \ln No - kt \qquad [5]$$

RESULTS AND DISCUSSION

Pre-Harvest Nutrient Distribution

Soil Chemistry

Significant differences in the chemical characteristics of the three soil types occurred. Differences between the two flatwoods soils (Mascotte and Stilson) were related to differences in pedogenic processes and horizon morphology. Extractable Al and Fe concentrations in the A1 horizon of the Mascotte soil were lower, and extractable Ca and Mg concentrations higher, than in the A1 horizon of the Stilson soil (Table 10). The concentrations of Fe and Al in the Mascotte soil increased in the subsurface soil horizons, particularly in association with the B2h horizon (Appendix B). Similar increases did not occur in Stilson subsurface soil horizons. The C/N ratio was significantly lower and the pH significantly higher in the Stilson soil than the Mascotte soil. This would tend to indicate that decomposition rates were higher in the Stilson soil. The lower organic matter concentration in the Stilson A1 horizon appears to confirm this hypothesis.

Extractable concentrations of all elements were lower in the A1 horizon of the Surrency soil than in the A1 horizon of either the Mascotte or Stilson soils (Table 11). Organic matter and extractable Al concentrations were high in Surrency soils and P was probably retained against extraction as a result of complexation. Extractable

Table 10 Comparisons of Mascotte and Stilson Al horizon chemical characteristics for the treatment and control watersheds prior to harvest and site preparation

Variable	Low intensity site preparation (WS 1) Mascotte	Low intensity site preparation (WS 1) Stilson	High intensity site preparation (WS-2) Mascotte	High intensity site preparation (WS-2) Stilson	Control (WS-3) Mascotte	Control (WS-3) Stilson	Comparisons among means
pH	3.9	4.5	3.8	4.3	3.8	4.4	S
Organic matter (%)	3.56	2.75	5.14	2.71	5.08	3.22	S
N (%)	0.06	0.06	0.08	0.06	0.08	0.07	
C/N ratio	39	29	37	22	36	28	[illegible]
P (ppm extractable)	2.7	2.6	3.0	3.6	3.4	2.0	
K (ppm extractable)	12.9	10.2	16.0	7.2	14.2	10.7	
Ca (ppm extractable)	94.7	59.6	73.3	15.2	106.2	44.9	[illegible]
Mg (ppm extractable)	29.3	11.1	29.8	6.0	41.2	15.1	S
Fe (ppm extractable)	15.6	35.1	21.3	32.5	16.8	47.5	S
Al (ppm extractable)	64.4	192.0	92.9	138.8	72.0	271.6 TC/	S

S – Differences between soils significant (α= 05)
TC – Treatment watersheds were significantly different from the control (α= 05)

Table 11. Comparisons of Surrency A1 horizon chemical characteristics for the treatment and control watersheds prior to harvest and site preparation

Variable	Low intensity site preparation (WS-1)	High intensity site preparation (WS-2)	Control (WS-3)	Comparisons among means
pH	4.0	4.1	4.2	
Organic matter (%)	13.5	5.8	9.7	TT
N (%)	0.23	0.17	0.20	
C/N ratio	36.4	20.4	27.1	TT
P	0.9	1.2	[illegible]	
K	5.8	7.9	[illegible]	
Ca	20.0	18.0	[illegible]	
Mg	9.8	8.[illegible]	[illegible]	
Fe	4.5	9.8	15.4	
Al	349.8	254.2	292.9	

TT - Differences between the two treatment watersheds were significant (α = .05).

Ca and Mg concentrations were also lower and may have also been due to complexation. Potassium can be directly leached from plant tissue and it was not surprising that its concentrations were lower in the frequently flooded Surrency soil than in the less frequently flooded flatwoods soils.

Only minor differences in chemical characteristics of Mascotte and Sapelo soils occurred between the three watersheds. The only significant difference was in Al concentrations which were higher in Sapelo soils of the control watershed than in the two treatment watersheds. There were, however, significant differences in Surrency soils between watersheds. Organic matter content ranged from a low of 5.8% in the watershed which was to be intensively prepared to a high of 13.5% in the watershed which was to be less intensively prepared. Nitrogen values ranged from 0.17% to 0.23% in these watersheds. These differences were consistent with the large variability previously reported for soils of cypress domes located in managed landscapes [a/] and probably reflected differences in drainage or overstory vegetation.

Ecosystem Storage and Distribution

The distribution of nutrients in the overstory and understory vegetation, forest floor, and mineral soil horizons were presented for each soil-vegetation association in Tables 12-14. Only minor differences in total nutrient content and distribution pattern existed between the two flatwoods soils. The marine sands from which these soils were developed were low in primary minerals and this was reflected

[a/] Marois, K. C. 1980. Natural and management related variation in cypress dome ecosystems, unpublished M.S. thesis, Univ. Florida, Gainesville.

Table 12 The distribution of macronutrients in a Mascotte soil-vegetation association[a/]

Component	N	P	K	Ca	Mg
	--------	--------	---total content, kg/ha---	--------	--------
Overstory vegetation[b/]					
Bole (113 metric ton/ha)	81	16.6	24.1	98	18
Branch (9.2 metric ton/ha)	12	1.0	3.5	14	2
Foliage (6.1 metric ton/ha)	25	1.2	2.3	8	4
Subtotal	118	18.8	34.9	120	[illegible]
Understory vegetation					
Stems (5.6 metric ton/ha)	13	1.4	4.8	24	[illegible]
Foliage (1.8 metric ton/ha)	16	1.1	3.4	8	3
Subtotal	29	2.5	8.2	32	8
Organic horizons					
O1 (16.7 metric ton/ha)[c/]	122 (11)[d/]	4.6 (.4)	4.4 (.4)	62 (6)	11 (2)
O2 (16.8 metric ton/ha)	144 (12)	5.0 (.6)	5.1 (.7)	34 (4)	10 (1)
Subtotal	266	9.6	9.5	96	21
Mineral soil			---extractable content, kg/ha---		
A1 (21.9 cm)[e/]	934 (112)	3.8 (.4)	18.2 (2.5)	118 (14)	43 (8)
A2 (13.6 cm)	425 (55)	3.1 (.3)	22.3 (2.4)	107 (17)	28 (3)
B2h (20.9 cm)	1109 (309)	3.3 (.4)	19.4 (4.7)	91 (18)	26 (5)
A21 (25.1 cm)	279 (80)	3.7 (.9)	18.2 (2.2)	55 (12)	18 (3)
B2t (10.5 cm)[f/]	242 (85)	0.6 (.2)	8.1 (2.2)	41 (11)	95 (26)
Subtotal	2989	14.5	85.2	412	210
Ecosystem total	3402	45.4	137.8	660	263

a/Average for the three watersheds
b/Overstory and understory weights and contents calculated from unpublished IMPAC data
c/Non ash-free
d/Standard error of estimate
e/Horizon thickness
f/To 1 m depth

Table 13 The distribution of macronutrients in a Stilson soil-vegetation association [a]

Component	N	P	K	Ca	Mg
	----------------------total content kg/ha----------------------				
Overstory vegetation[b]					
Bole (183 metric ton/ha)	130	27 1	39 5	158	29
Branch (17 7 metric ton/ha)	24	2 0	8 3	28	5
Foliage (9 9 metric ton/ha)	42	2 0	12 0	15	7
Subtotal	196	31 1	59 8	201	[illegible]
Understory vegetation					
Stem (3 1 metric ton/ha)	10	0 8	2 9	16	[illegible]
Foliage (0 9 metric ton/ha)	10	0 5	2 1	6	[illegible]
Subtotal	20	1 3	5 0	22	[illegible]
Organic horizons					
O1 (18 7 metric ton/ha)[c]	133 (10)[d]	5 2 (0 4)	4 7 (0 3)	67 (4)	11 (1)
O2 (17 6 metric ton/ha)	154 (24)	5 0 (0 5)	4 1 (0 5)	30 (4)	7 (1)
Subtotal	287	10 2	8 8	97	18
Mineral soil[e]		-------extractable content kg/ha-------			
A1 (9 4 cm)[e]	711 (57)	2 6 (0 5)	10 9 (0 9)	52 (16)	13 (4)
A2 (53 3 cm)	1385 (220)	32 2 (15 1)	32 8 (2 2)	126 (31)	31 (3)
B21 (15 8 cm)	161 (40)	19 3 (18 6)	9 8 (1 4)	51 (15)	21 (3)
B2t (21 5 cm)[f]	608 (265)	1 2 (0 4)	16 7 (4 3)	115 (65)	136 (68)
Subtotal	2865	55 3	70 2	344	201
Ecosystem total	3368	97 9	143 8	664	265

a/Average for the three watersheds
b/Overstory and understory weights and contents calculated from unpublished IMPAC data
c/Non ash-free
d/Standard error of estimate
e/Horizon thickness
f/To 1 m depth

Table 14. The distribution of macronutrients in a Surrency soil-vegetation association [a]

Component	N	P	K	Ca	Mg
	----------------------total content, kg/ha----------------------				
Overstory vegetation [b]					
Bole (127 metric ton/ha)	122	17.0	37.2	154	77
Branch (11.6 metric ton/ha)	20	1.5	6.1	31	[illegible]
Foliage (7.5 metric ton/ha)	39	1.8	11.0	22	16
Subtotal	181	20.3	54.3	207	[illegible]
Understory vegetation					
Stem (12.1 metric ton/ha)	39	3.1	13.6	73	10
Foliage (1.8 metric tons/ha)	15	0.7	4.7	14	3
Subtotal	54	3.8	18.3	87	13
Organic horizons					
O1 (50.6 metric ton/ha) [c]	792 (101) [d]	18.7 (2.4)	15.7 (2.4)	56 (7)	[illegible]
O2 (224.6 metric ton/ha)	2666 (499)	64.4 (12.6)	47.4 (12.1)	112 (58)	[illegible]
Subtotal	3458	83.2	63.1	168	[illegible]
	--------extractable content, kg/ha--------				
Mineral soil [e]					
A1 (30.3 cm)	4296 (388)	2.2 (0.4)	16.9 (2.6)	35 (6)	18 ([illegible])
A2 (40.6 cm)	705 (153)	1.8 (0.3)	28.8 (3.8)	54 (7)	27 (6)
B2t (29.1 cm) [f]	1972 (454)	2.7 (1.0)	67.0 (14.2)	39 (19)	268 (7?)
Subtotal	6973	6.7	112.7	188	313
Ecosystem total	10666	113.9	248.4	650	463

a/Average for three watersheds
b/Overstory and understory weights and contents calculated from unpublished IMPAC data
c/Not ash-free
d/Standard error of estimate
e/Horizon thickness, B2t to 1 m depth
f/To 1 m depth

by low soil K, Ca, and Mg contents. Soil P was also low, particularly in the mineral horizons of the Mascotte soil which contained only 14.5 kg/ha extractable P. Phosphorus is readily adsorbed by organo-metal complexes in the spodic horizon (Pritchett, 1979) and the overall decrease in extractable P may have been due to accumulation of insoluble forms in this horizon. The N contents of the Mascotte and Stilson soil-vegetation associations were also low. They were somewhat higher than previously reported for flatwoods by Burger (Table 1), but were based on a deeper profile.

The relative quantities of nutrients in the four major components differed for the two flatwoods soils. Larger quantities occurred in the overstory vegetation of the Stilson soil-vegetation association than in the Mascotte association reflecting better tree stocking on Stilson soils. A somewhat denser understory occurred on Mascotte soils and nutrient contents were correspondingly higher in this component. The total extractable nutrient contents of the organic and mineral soil horizons were almost identical.

Nutrient storage in the organic and mineral soil horizons of the Surrency soil (Table 14) was relatively large. The N content of these horizons averaged over 10,000 kg/ha. This was 3 times greater than N storage in either of the flatwoods soils, and would appear to indicate that N was accumulating at much faster rates than in the flatwoods. Apparently, decomposition and mineralization were slow in these soils. This, coupled with a low soil pH which inhibited nitrification and a low fire susceptability, could have prevented large gaseous N losses through denitrification and volatilization

and resulted in the relatively high N storage. Phosphorus and K contents were also greater, but in much lower proportions.

Slash pine is shade intolerant and self prunes readily. This was reflected by the relatively small quantities of nutrients stored in overstory branches and foliage of this forest. Less than 35% of the total overstory N content and 13% of the total overstory P content were associated with these components on the Mascotte and Stilson soils. The relative contribution of branch and foliage components to the total overstory nutrient storage was only slightly greater than this on the Suttency soil. These percentages are lower than percentages which have been reported for sites characterized by shade tolerant conifers (Westman and Webber, 1972, Foster and Morrison, 1976, Green and Grigal, 1980) or hardwoods (Duvigneaud and Denaeyer-DeSmet, 1970, Whittaker et al., 1979). Reported percentages for N and P range from 60-70% and 20-55%, respectively, on these sites. Percentages reported for stands of other southern pine species are generally between values reported by these investigators and the values reported for flatwoods in this study. For instance, Wells and Jorgensen (1975) reported that 55% of the total N and 52% of the total overstory P was in branches and foliage of the 16 year old loblolly pine plantation. From these data, it can be concluded that total above-ground harvests would increase nutrient removal above removals occurring in bolewood-only harvests proportionately less on flatwoods sites than in most forest ecosystems.

The nutrient content of the understory vegetation and organic soil horizons was twice as large as the overstory nutrient content on both the Mascotte and Stilson soil. This represented over 10% of the

measured nutrient reserves of the site. Harvest or site preparation activities which remove these materials from the planting surface could rapidly deplete the nutrient reserves of the site.

Harvest Removals

Swindel et al. (in press) estimated biomass removals from the two harvested watersheds based on regressions developed using data collected on the 27 permanent biomass plots in conjunction with a 1% cruise. Predicted values were 101 and 137 metric tons/ha (green weight) from the less intensively and intensively managed watersheds, respectively. These estimates compared reasonably well with actual weights recorded at the woodyard of 104 and 112 metric tons/ha, respectively. Much of the difference between the observed and predicted yields appeared to be related to harvesting pond edges and the contribution to these differences by the two harvesting techniques was probably small.

Nutrient removals during harvest were estimated from the data presented in Tables 12 and 13 using the simplifying assumption that there was no difference in bolewood removals due to harvesting method. The average removals from the two watersheds, based on the relative proportion of Mascotte and Stilson soils and 88% overall merchantability (calculated from Swindel et al., in press), were 95, 17.4, 25.3, 102, and 15 kg/ha of N, P, K, Ca, and Mg, respectively. These removals compare favorably with reported removals for other natural stands of slash pine (Burger, 1979), but are considerably less than removals from fertilized slash pine plantations (Pritchett and Smith, 1974).

Red and black spruce (*Picea rubens* Sarg and *P. mariana* (Mill) B S P) stands of the boreal forest are the only ecosystems for which lower nutrient removals have been reported for bolewood harvests (Weetman and Webber, 1972)

Conventional wisdom holds that branches and foliage are a major nutrient sink It has been suggested that removal of these materials during complete tree harvests pose a serious nutrient depletion threat (Boyle and Ek, 1972; Kimmins, 1977; Abst et al , 1978). These data do not support this contention In contrast to sites in the boreal forest where complete above-ground tree harvests can remove 300% more N and P than a merchantable bolewood harvest (Weetman and Webber, 1972), complete above-ground tree removal would increase N and P removal only 47% and 14%, respectively The 125 kg/ha of N which would be removed from the two watersheds would be equalled by atmospheric inputs in about 20 years.

Post-Harvest Nutrient Distribution

Displacement During Windrowing of the Intensively Prepared Watershed

Windrow dimensions. Approximately 5.2 km of windrow were formed on the 36 ha which were harvested in the intensively prepared watershed (Table 15). The mean cross-sectional area of these windrows was 2.47 m^2. This value is very close to the 2 52 m^2 average determined by McNab (1980) over a range of windrowed sites in the lower piedmont of Georgia, and would indicate that the windrows were fairly typical in size.

Windrow composition The weight of each component in a 1-m wide cross section was predicted as a function of windrow cross-sectional area (Fig 7) A linear-no intercept model (Eq [2] (p 59) adequately

Table [illegible] [illegible] during intensive [illegible]

Area harvested	35.6 ha
Windrow length	5213 m (246.4 m/ha)
Windrow area	2.2 ha (621 m^2/ha)
Mean cross-sectional area	[illegible] 47 m^2
Mean width	4.2 m

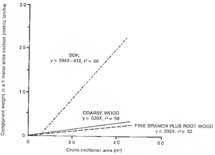

Fig. 7 - Predicted relationships between component weight and [illegible] cross-sectional area

predicted the relationship of both the bolewood and fine branch plus rootwood components to cross-sectional area. This model satisfied the premise that windrows of zero cross-sectional area had zero component weight. The choice of the regression model to be used for describing the relationship between soil weight and cross-sectional area was more difficult. Both the linear model with an estimated intercept Eq. [3] and the quadratic zero-intercept Eq. [4] model resulted in r^2 values of about .90 (Fig. 8). The linear model was chosen for subsequent analyses because it provided more conservative estimates at very large cross-sectional areas, and reflected the observation that small windrows ($< 75\ m^2$) did not contain appreciable quantities of soil.

From Fig. 7 it is evident that a windrow of average cross-sectional area ($2.47\ m^2$) contained about 10 times more soil (by weight) than either of the other two components. The soil-to-woody material ratio increased as the size of the windrow increased.

An average of 153 metric tons/ha of soil material were moved during the windrowing operation (Table 16). Glass (1976) estimated that 5 cm of topsoil was displaced during construction of windrows in the Piedmont of North Carolina. Assuming a bulk density of 1.2, this thickness would correspond to 600 metric tons/ha of displaced soil material. Similar analyses applied to windrowing operations in north-central Florida reported by Burger (1979) result in an estimated displacement of 300 metric tons/ha of soil and litter. Thus, the estimated removals in Table 16 do not appear unusually large.

<u>Nutrient concentration and content</u>. The nutrient concentrations of the coarse wood and fine branch plus root wood components (Table 16)

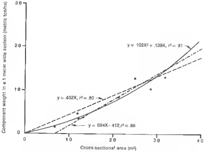

Fig. 8 - Comparison of the regression models for estimating soil weight from measurements of windrow cross-sectional area

Table 16 Average nutrient concentrations and contents of windrows formed during intensive site preparation of watershed 2 by component

Component	Organic matter	N	P	K	Ca	Mg
	-- concentration,% -		------------- concentration,ppm -- -			
Soil[a]						
(extractable)	ND	ND	12	70	427	121
(total)	17.9	0.20	91	105	770	187
Coarse wood (total)	ND	0.18(0.05)[b]	108(44)	362(97)	1077(315)	366(12[illegible])
Fine branch plus root wood (total)	ND	0.39(0.10)	192(40)	523(143)	2535(571)	612(140)
	-----------------	---------	total content, kg/ha	------------------		
Soil (153.9 metric ton/ha)	ND	303	13.9[c]	16.1	118.4	28.7
Coarse wood (14.0 metric ton/ha)	ND	25	1.5	5.1	15.0	5.1
Fine branch plus root wood (11.7 metric ton/ha)	ND	45	2.2	6.1	29.5	[illegible]
Total content		373	17.6	27.3	162.9	40.9

[a] For a windrow of mean cross-sectional area
[b] Standard deviation
[c] Calculations based on total P, K, Ca, and Mg

are similar to the concentrations reported for [illegible] and branch wood of standing slash pine on this site (Appendix C). Total N and extractable P, K, Ca, and Mg concentrations of the soil component were, however, much higher than reported for the A1 horizons of the two flatwoods soils prior to disturbance (Table 10). This undoubtedly resulted from the large quantity of surface litter and partially decomposed slash which was mixed with mineral soil during the windrowing operation. The quantity of this material can be estimated to be 23 metric ton/ha on the basis of the difference between the A1 horizon soil and windrow soil organic matter concentrations. Small windrows contained a higher proportion of these nutrient-rich materials than large windrows, hence, they had higher nutrient concentrations in the soil compartment.

Direct regressions of nutrient content against cross-sectional area (Fig. 9) were used in conjunction with measured cross-sectional areas to calculate the average nutrient contents of windrows on an area basis (Table 16). The displacement of nutrients during the windrowing operation roughly paralleled the displacement of the individual components. Most of the nutrients displaced were moved with the soil component. The 303 kg/ha N moved with the soil component was approximately 10 times greater than the N moved with either of the woody components. The displacements of P, K, Ca and Mg were also highest in the soil component, although in lower respective proportions. Slightly greater quantities of all nutrients were moved with the fine branch and root wood than were moved with the coarse wood component.

The 373 kg/ha of N displaced by windrowing was more than 10 percent of the total N content of this flatwoods ecosystem. Moreover, much of

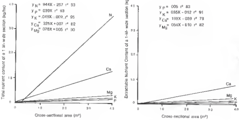

Fig 9 - Predicted relationships between nutrient content of the [illegible] and windrow cross-sectional area

the N removed was a part of the litter layer and surface soil which may be disproportionately important to the nutrition of the young plantation. The P, K, Ca, and Mg contents of the windrow represented a displacement of between 20 and 40 percent of the total nutrient reserves of the ecosystem (Tables 13-14). These percentages would have been lower if the total P, K, Ca, and Mg in the mineral soil, rather than the extractable fraction, were used to calculate soil reserves. Nevertheless, these displacements were significant, exceeding the harvest removals of all macronutrients. No natural mechanism for effectively returning these nutrients to the windrow area exists and these displacements represented unnecessary removals from the planting surface.

<u>Nutrient Reserves in the Young Plantation</u>

<u>Mineral soil</u>. The impacts of harvesting and site preparation on the nutrient reserves of the mineral soil were evaluated by resampling the surface (organic and A1 or Ap) horizons of the permanent plots on the Mascotte and Stilson soils. Most differences were small. The most significant effects were physical (Table 17). The bulk density of the surface soil horizon was increased an average of 0.08 g/cm^3 on the harvested and site prepared watersheds. Although the site preparation x soil interaction was not statistically significant (α = .05), it does appear that the Mascotte soil bulk density was more sensitive to intensive site preparation than the Stilson soils. The destruction of macropores during the disking operation, followed by soil settling during wet periods, was probably responsible for much of the observed increase in bulk density. This process would be expected to influence the Mascotte soil, which had a lower initial bulk density and was wetter,

Table 17. Physical and chemical characteristics of the unbedded surface horizon of two flatwoods soils one year after site preparation and planting.

Variable		Low intensity site preparation (WS-1) Mascotte	Low intensity site preparation (WS-1) Sellers	High intensity site preparation (WS-1) Mascotte	High intensity site preparation (WS-1) Sellers	Control (WS-3) Mascotte	Control (WS-3) Sellers	Comparisons among means
Bulk density (g/cm³)		1.02[a]	1.24	1.22	1.27	1.07	1.18	S, TC
Average horizon depth (cm)		11.5	11.5	12.3	12.5	10.5	10.6	TC
pH		4.45	4.46	4.29	4.63	4.43	4.51	
OM (%)		5.23	2.64	4.40	3.03	5.24	3.[illegible]	
Total N		0.082	0.061	0.070	0.073	0.084	0.068	
C/N ratio		38	26	37	24	38	28	
P	ppm extractable	1.6	3.4	1.1	0.9	1.7	1.3	
K	ppm extractable	18.1	12.5	19.5	15.5	17.3	10.9	
Ca	ppm extractable	116.5	48.8	110.7	64.3	122.4	46.1	
Mg	ppm extractable	56.8	13.1	40.4	21.9	53.1	16.3	
Fe	ppm extractable	14.5	64.3	31.8	57.4	14.3	46.1	
Al	ppm extractable	93.1	374.7	107.5	360.8	98.7	326.1	

[a] Least-squares means.

S - Differences between soils significant (α = .05)

TC Treatment watersheds were significantly different from the control (α = .05).

to a greater degree than the Stilson soil. The surface horizons of the prepared watersheds were also deeper than the A1 horizon of the control watershed as a result of A1 and A2 horizon mixing during the chopping (both watersheds) and disking (intensively prepared watershed) operations.

Additions of nutrients to the forest floor as logging slash, or their removal during the windrowing operation, were not detected by increases or decreases in the organic matter concentration, nutrient concentration, or C/N ratio of the mineral soil (Table 17). Failures to measure significant differences in the nutrient concentration of mineral soils of unbedded areas have been reported elsewhere (Haines and Pritchett, 1965, Shultz, 1976). Apparently, mineralization transfer of nutrients from residual slash to the soil proceeded too slowly to measurably alter soil chemistry of the less intensively prepared site, and enough mixing of fertile with infertile soil occurred during the windrowing operation of the intensively prepared site to offset any downward bias in nutrient concentrations of the residual material.

The nutrient contents of the mineral soil in the treated watersheds were, with the exception of K, not significantly different from the undisturbed control (Table 18). A trend toward increased contents in the treated watersheds, which roughly paralleled the aforementioned increases in surface soil depth, existed. This increase was significant for K which averaged 24 kg/ha on the prepared watersheds versus 16 kg/ha on the control. It appears this resulted from the combined effect of two factors: (1) measured increases in surface soil depth resulting from A1 and A2 horizon mixing, and (2) enrichment of K in the surface soil due to accelerated leaching of slash and litter materials.

Table 18 Nutrient content of the unbedded surface soil horizon of two flatwoods soils (exclusive of litter and slash) one year after site preparation and planting

Nutrient	Low intensity site preparation (WS-1)		High intensity site preparation (WS-2)		Control (WS-3)		Comparisons among means
	Mascotte	Stilson	Mascotte	Stilson	Mascotte	Stilson	
	kg/ha						
N	1009[a/]	853	1013	1142	923	860	
P	1.9	4.8	1.7	1.5	1.9	1.7	
K	22	18	29	25	19	17	[illegible]
Ca	149	68	164	102	141	58	[illegible]
Mg	70	18	58	34	60	20	[illegible]

a/ Least-squares means.

S - Differences between soils significant (α = .05)

TC - Treatment watersheds were significantly different from the control (α = .05)

Litter plus slash. The quantities of residual slash plus litter were significantly reduced by the harvesting and site preparation treatments (Table 19). Only eight metric ton/ha of organic materials remained on the surface of the Stilson soil after intensive site preparation. The bulk of the litter plus slash was either burned or scraped from the planting surface during the windrowing operation. Similar reductions were not measured on the less intensively prepared watershed. It should be pointed out that 35 - 40 metric ton/ha of debris was left on the soil surface following the less intensive shortwood logging. Little evidence of this addition existed, and we can conclude that decomposition roughly equalled this input during the two year period between harvest and sampling. Lower quantities of materials remained on the Mascotte soil than remained on the Stilson soil reflecting pre-harvest differences in the amounts of branches and foliage in the undisturbed forests on these soils (Tables 12 and 13).

The nutrient concentrations of litter plus slash materials from the less intensively prepared watershed were always slightly higher than their counterparts from the intensively prepared watershed (Table 20). On the intensively prepared watershed, fine organics were burned, removed from the planting surface by windrowing, and more rapidly decomposed as a result of thorough mixing with the mineral soil. The debris remaining on this watershed tended to be coarser materials with lower nutrient concentrations. These differences may also reflect sampling bias. On the less intensively prepared watershed fine organics could be removed from the soil surface relatively easily because the forest floor was intact. These materials were difficult to separate from the mineral soil on the windrowed and disked site and biased the sample toward coarser materials which had lower nutrient concentrations.

Table 19 Weight of litter and residual logging slash remaining on the unbedded areas of two flatwoods soils one year after site preparation and planting

Low intensity site preparation (WS-1)		High intensity site preparation (WS-2)		Control (WS-3)[a/]		Comparisons among means
Mascotte	Stilson	Mascotte	Stilson	Mascotte	Stilson	
kg/ha						
33710[b/]	44330	4160	8020	38370	28926	S, TC, TT

a/ From 1977 collections.

b/ Least-squares means

S - Differences between soils significant (a = .05)

TC - Treatment watersheds significantly different from the control (a = .05)

TT - Differences between the two treatments were significant (a = .05)

Table 20. Average nutrient concentrations and contents of litter plus residual slash in the two harvested watersheds one year after site preparation and planting.

Nutrient	Low intensity site preparation (WS-1)	High intensity site preparation (WS-2)
	------------ concentration ------------	
N (%)	0.451[a]	0.375
P (ppm)	216	133
K (ppm)	190	151*
Ca (ppm)	2598	1622*
Mg (ppm)	481	353*
	------------ total content, kg/ha ------------	
N	184	22*
P	8.0	0.7*
K	6.9	0.9*
Ca	92	11*
Mg	18	2*

*Significant difference between means (α=.05)
a/Least-squares means

Differences in nutrient content paralleled those of litter and slash weight. Nitrogen, P, K, Ca, and Mg contents were an order of magnitude larger on the less intensively prepared watershed than they were on the intensively prepared watershed (Table 20). Mälkönen (1976) pointed out that the nutrient reserves associated with litter and slash are of greater importance to seedling nutrition than would be indicated by simple comparisons with mineral soil nutrient content. Most nutrients in the mineral soil occur in relatively stable compounds which, in contrast to litter and slash, are relatively resistant to decomposition and mineralization. Although the overall impact of the intensive site preparation was small, it did severely reduce the quantities of nutrients associated with this fraction. An attempt was made to determine the contribution which burning made to this reduction. Unfortunately, sampling variability was too large to allow a reasonable estimate to be made.

Localization of Nutrients During Bedding

Mineral soil. The effects of bedding on surface soil characteristics were not dependent on site preparation or soil type. The surface soil bulk density was decreased an average of 0.09 g/cm^3 (Table 21). As the effect of site preparation activities conducted prior to bedding had been to increase bulk density (Table 17), bedding offset these increases. However, care should be exercised in interpreting this effect as the values reported in Table 21 are averages for the entire bed. Bedding did not reduce the bulk density of the horizon over which the beds had been formed, thus, the bulk density of the bed surface must have been lower than the average for the net effect to be zero.

Table 21. The average influence of bedding on physical and chemical characteristics of the surface soil of the two site prepared watersheds.

Variable	Interbed	Bed
Average depth of the surface soil (cm)	11.9	16.8*
Average soil depth at crown of the bed (cm)	NA	21.0*
Bulk density (g/cm^3)	1.20	1.11*
Width (cm)	154	139
pH	4.46	4.50
Total N (%)	0.071	0.079
P (ppm extractable)	1.8	2.0
K (ppm extractable)	16.4	18.1
Mg (ppm extractable)	33.0	41.9*
Fe (ppm extractable)	42.0	37.8
Al (ppm extractable)	234.0	233.1

*Significant difference between means (α=.05)

The low bulk densities near the surface of the bed may have contributed to poorer seedling survival on the less intensively prepared watershed (see p. 146). Slight increases in macronutrient concentrations were observed, but for the most part, these increases were not statistically significant. Significant increases in soil macronutrient concentrations have been reported in beds elsewhere in the Southeast (Haines and Pritchett, 1965, Shultz, 1976). The values presented in Table 21 are averages for the entire surface profile and include material both from within the bed and from within the A1 horizon over which the bed was formed. Thus, the measured concentration differences between the bed and interbed area were reduced, perhaps below statistical significance.

The effect of bedding on soil Ca concentrations depended on the other site preparation treatments (Table 22). Soil Ca concentrations were higher in the beds formed on the less intensively prepared watershed. One explanation can be offered for this inconsistency. Species of Lyonia, which are characterized by relatively high concentrations of Ca in foliage (Appendix C), were common on the less intensively prepared watershed. This material would be fairly easily incorporated into beds where it could help increase Ca concentrations. Most of this material was bladed from the site on the intensively prepared watershed.

The contents of total N, and extractable P, K, and Mg were between 40% and 60% greater in the beds than in the interbed area (Table 23). These increases represented the combined effects of increased nutrient concentrations and physical increases in surface soil depth. The interaction between soil Ca content and bedding was significant and paralleled the patterns of concentration differences previously discussed (Table 22).

Table [illegible]. The interacting effect of bedding and pre-bedding site preparation on extractable Ca concentration and content of the surface soil [a]

Site Preparation	Interbed	Bed
	--concentration, ppm--	
Low intensity site preparation (WS-1)	82.3	126.4*
High intensity site preparation (WS-2)	87.4	88.7
	-----content, g/m^2----	
Low intensity site preparation (WS-1)	10.9[a]	21.8*
High intensity site preparation (WS-2)	13.3	16.7

[a] Based on depths presented in Table 21.

*Significant difference between means (α = .05).

Table [illegible]. The effect of bedding on N, P, K, and Mg contents of the surface soil a/

Nutrient		Interbed	Bed
		g/m^2	
N	(total)	100	143*
P	extractable	0.42	0.37*
K	extractable	2.3	3.2*
Mg	extractable	4.5	7.4*

a/ Based on depths presented in Table 21

* Significant difference between means (α = .05).

<u>Litter and slash</u> The amounts of litter and slash localized in the beds depended on both soil type and site preparation. Relative increases in the weight of organic materials were greatest on the intensively prepared site (Table 24). The weight of litter and slash materials within beds on Mascotte soils was three times greater than in the interbed areas. A two-fold increase in litter weight was observed for beds on the Sellers soils. In contrast, bedding increased litter weight only 49% on Mascotte soils, and resulted in a measured decrease in total detritus weight on Sellers soils, in the less intensively prepared site. It was unlikely that bedding stimulated decomposition to the degree where a measurable decrease in total slash plus litter weight would occur. The decrease was undoubtedly due to the incorporation of fine organics, which were measured as litter on the interbed areas, into the soil component of the beds. This incorporation of fine organics into the mineral component of the bed resulted in a lower nutrient concentration in the remaining litter and slash materials because they tended to be coarser materials (Table 25).

The larger quantities of litter and slash associated with the beds more than compensated for the lower concentrations and were reflected by increases in nutrient content (Fig. 10). The 3-way interaction between bedding, site preparation, and soil type was significant for all macronutrients except N. Increases in the nutrient content of the litter plus slash were discernable in beds on both soils in the intensively prepared watershed, but were restricted to the Mascotte soil in the less intensively prepared watershed.

Most of the increases in bed nutrient contents were associated with the increases in the depth of the mineral soil and the increased

Table 24. The interaction of bedding, soil type, and site preparation on the weight of litter plus slash

Site Preparation	Soil Type	Interbed	Bed
		——— g/m^2 ———	
Low intensity site preparation (WS-1)	Mascotte	3371[a]	5034
	Stilson	4433	3522
High intensity site preparation (WS-2)	Mascotte	418	1472
	Stilson	802	1588

[a]Least-squares means

[illegible] The average influence of bedding on total nutrient concentrations of litter plus slash

Nutrient	Interbed	Bed
N (%)	0.41	0.33*
P (ppm)	174	149
K	171	159
Ca	2110	1567*
Mg	417	328*

* Significant difference between means (α = .05).

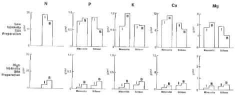

Fig 10 - Nutrient contents of litter plus slash in the bed (B) and interbed (I) areas of the two site prepared watersheds at the end of the first post-treatment year (first growing season)

nutrient concentrations of this material (Table 21). The increases in bed nutrient contents above interbed nutrient contents contributed by litter plus slash were small. On this basis it could not be concluded that the bedding increased nutrient availability in young plantation through slow release of nutrients stored in these organic materials. Rather, such increases would have to be attributed to increases in the quantities or form of nutrients stored and released from the mineral soil, and to changes in microclimatic conditions within the bed.

Soil Solution Chemistry of the Natural and Disturbed Forests

Impacts of Harvest and Site Preparation on Mascotte and Stilson Soils

Changes in the surface horizon. The pH, conductivity, NH_4-N, NO_3-N, and PO_4-P concentrations of soil solution collected from the surface horizon of the flatwood soils are presented in Fig. 11-20. The values presented are mean values for solution collected from the base of the A1 horizon. All samples were collected from the interbed areas of the monitoring plots, thus, they provide a means of comparing differences between site preparation without the confounding effects of bedding. Separate statistical analyses were completed for each sampling period. The results of these analyses are presented in Appendix D.

The soil solution pH of the Mascotte soil generally ranged between 3.5 to 4.5 (Fig. 11). The pH values in the Stilson soil were consistently higher (Fig. 12) and ranged from a low of 3.7 to a high of 6.1. The variability between sampling periods was large. Strong increases or decreases in the pH generally occurred simultaneously on all watersheds. These changes did not appear to be correlated with wet or

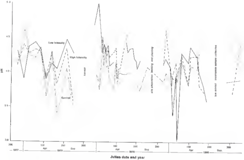

Fig. 11. Soil solution pH in the surface horizon of the Mascotte soil during the control, treatment, and first post treatment years

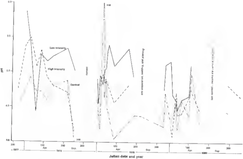

Fig. 12 — Soil solution pH in the surface horizon of the Stilson soil during the control, treatment, and first post-treatment year

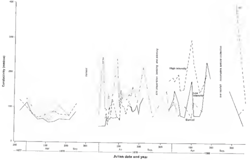

Fig. 13 - Soil solution conductivity in the surface horizon of the Mascotte soil during the control, treatment, and first post-treatment years

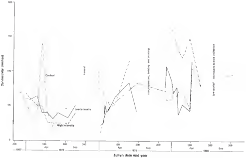

Fig. 14 - Soil solution conductivity in the surface horizon of the Stilson soil during the control, treatment, and first post-treatment years

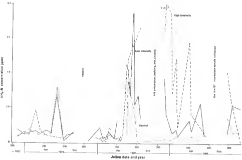

Fig. 15 Soil solution NH_4-N concentration in the surface horizon of the Mascotte soil during the control, treatment, and first post treatment years.

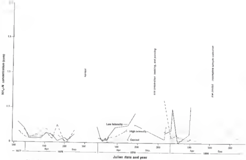

Fig. 16 Soil solution NH_4-N concentration in the surface horizon of the Stilson soil during the control, treatment, and first post-treatment years

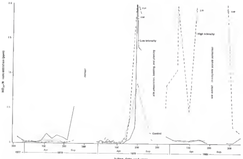

Fig. 17 - Soil solution NO_3-N concentration in the surface horizon of the Mascotte soil during the control, treatment, and first post-treatment years

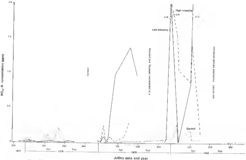

Fig. 18 Soil solution NO_3-N concentration in the surface horizon of the Stilson soil during the control, treatment, and first post-treatment years.

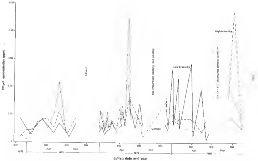

Fig. 19 – Soil solution PO_4-P concentration in the surface horizon of the Wascotte soil during the control, treatment, and first post treatment years.

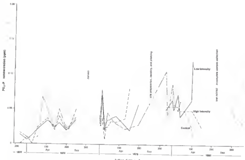

Fig. 20 - Soil solution PO_4-P concentration in the surface horizon of the Stilson soil during the control, treatment, and first post-treatment years

dry seasons. Changes in pH were mirrored by changes in conductivity, which increased when pH decreased, due to the larger quantities of H ions in solution (Fig. 13-14). Higher conductivities were also characteristic of soil solution from the more acid Mascotte soils.

The impacts of harvest and site preparation on soil solution pH were minor. The only significant response occurred during the early part of 1980 after the sites had been planted. On two dates the solution pH in Mascotte soils of the less intensively prepared site dropped below 3.5. Simultaneous, but smaller, decreases were observed on the other two watersheds. The large magnitude of this decrease in the less intensively prepared watershed may have been due to leaching of organic acids from slash and litter left on the site by heavy precipitation. Significant increases in conductivity occurred on the treatment watersheds at about the same time (Fig. 13-14). This increase was largest in the less intensively prepared watershed and is consistent with the hypothesis of accelerated organic acid leaching during this period.

There were no significant differences in either NH_4-N or NO_3-N concentrations between watersheds or soil types during the calibration year (1979-1978). Ammoniacal-N concentrations ranged between 0.1 and 0.7 ppm and were generally less than 0.2 ppm (Fig. 15-16). The concentrations of NO_3-N were much lower, seldom exceeding 0.1 ppm (Fig. 17-18). Increases in both NH_4-N and NO_3-N concentrations occurred during the spring following harvest. The concentrations of NH_4-N peaked at about 2.0 ppm in Mascotte soils on the treated watersheds. Peak concentrations of NO_3-N of over 2.0 ppm also occurred in Mascotte soils of both watersheds during this period.

Peak NH_4-N and NO_3-N concentrations during the spring following harvest were much lower in Stilson soils than the Mascotte soils. The NH_4-N peak only reached 0.24 ppm in the less intensively prepared watershed, although NO_3-N concentration peaked at almost 1.5 ppm. No NH_4-N peaks were observed in Stilson soils on the intensively prepared watershed. Solution samplers were removed during the summer of the treatment year while the area was being site prepared and samples were not collected for that period. However, it does appear that NH_4-N and NO_3-N concentrations had peaked in the spring and were beginning to decrease.

Inorganic N concentrations rose again following the site preparation operations and remained at elevated levels throughout most of the first growing season. The partitioning of N between ammoniacal and nitrate forms was different for the two soils. Ammoniacal-N concentrations were greatest in the intensively prepared Mascotte soils, reaching a peak concentration of 2.12 ppm. Ammoniacal-N concentrations in Mascotte soils on the less intensively prepared site were greater than in the control watershed, but substantially lower than in the intensively prepared watershed. No increases in NO_3-N concentration were observed in soil solution from Mascotte soils in the less intensively prepared site, although NO_3-N reached a peak concentration of 3.42 ppm in the intensively prepared site on one occasion.

Partitioning between the two forms of inorganic-N were reversed in the Stilson soils. Nitrate-N concentrations, rather than NH_4-N, were elevated in Stilson soils and peaked at 2.4 and 4.3 ppm on the less intensively prepared and intensively prepared watersheds, respectively. The concentration of NH_4-N did not rise above 0.3 ppm in Stilson soils

of the less intensively prepared watershed until the end of the post-treatment year and failed to exceed 0.2 ppm in the intensively prepared watershed.

The magnitude and duration of inorganic N increases were not very different from patterns reported by Burger (1979) and Pritchett (1981) in similar studies. The observed differences in partitioning of N into its ammoniacal and nitrate forms is a new finding. At near neutral pH, ammonification is the rate limiting step in N mineralization and little NH_4 builds up in the soil (Alexander, 1981). However, it has been demonstrated that a pH of 4.5 can be considered the threshold value in flatwoods soils (Burger, 1979). At a pH greater than this value, nitrification will occur rapidly. The average soil solution pH in Mascotte soils was below 4.5 whereas the average soil solution pH in Stilson soils was greater than 4.5. Apparently, nitrification was inhibited in Mascotte soils but proceeded at reasonable rates in the Stilson soil. This difference may be important. Nitrate is not tightly held by the exchange complex of the soil and would be more readily leached from the soil than NH_4. Runoff from forest lands with a high percentage of Stilson soil, or similar soils, might be expected to contain more NO_3 than runoff from areas characterized by acid spodosols similar to the Mascotte series.

Inorganic P concentrations were low throughout the entire research period (Fig. 19-20). Small increases were observed following mechanical site preparation in both watersheds, but these increases were only significant in one instance.

Bedding effects. The degree to which bedding increased nutrient availability was evaluated by comparing nutrient concentrations of solution samples collected at the base of the Al horizon under the beds with those collected at the base of the Al horizon in the interbed areas of the plots. Bedding significantly reduced the soil solution pH by 0.2 units on both soils and in both watersheds. Previously discussed differences in inorganic N concentrations between watersheds and soils were accentuated by the bedding operation. The concentrations of NH_4-N in soil solution were significantly increased under beds on both soils in the intensively prepared watershed, but the magnitudes of the increases were much greater in the Mascotte soil (Table 26). The concentrations of NO_3-N were greater under beds on Sellers soils. These data appear to confirm the hypothesis that the bedding increased nutrient availability.

Changes within the soil profile. Chemical characteristics of soil solution from the major diagnostic horizons of each soil are presented in Tables 27-29 by water year. The general patterns of increasing pH and decreasing average nutrient concentrations with depth were not unexpected, having been previously reported on similar soils (Burger, 1979). Absolute increases in mean NH_4-N and NO_3-N concentrations occurred in every horizon of both flatwoods soils following harvest and site preparation. Mean annual concentrations in the subsurface soil were highest during the 1979-80 water year corresponding with the previously noted peak concentrations in the surface horizons.

The relative concentrations of NH_4-N in the A and B horizons of the Mascotte soils were apparently altered by management activities on

Table [illegible]. Mean annual soil solution inorganic N concentrations in bedded and interbedded areas of the site prepared and planted watersheds during the first post-treatment year.

Site preparation	Soil type	Interbed		Bed	
		NH_4-N	NO_3-N	NH_4-N	NO_3-N
Low intensity site preparation (WS-1)	Mascotte	0.30[a]	0.05	0.31	0.28
	Stilson	0.31	1.03	0.11	1.65*
High intensity site preparation (WS-2)	Mascotte	0.92	1.39	1.90*	1.66
	Stilson	0.11	0.93	0.37	3.80*

a/Least-squares means.

* Significant differences between means for the same N form (a = .05).

Table 27. Mean annual soil solution chemistry of the Mascotte soil by horizon during the control (1977-78), treatment (1978-79), and first post treatment (1979-80) years

Soil Horizon	Low Intensity Site Preparation (WS 4) pH	Cond	NH_4-N	NO_3-N	Tot-N	PO_4-P	Tot-P	High Intensity Site Preparation (WS 1) pH	Cond	NH_4-N	NO_3-N	Tot-N	PO_4-P	Tot-P	Control (WS 1) pH	Cond	NH_4-N	NO_3-N	Tot-N	PO_4-P	Tot-P
		mmho	ppm						mmho	ppm						mmho	ppm				
								1977-78													
A1	4.2	14	24	08	--	08[a]		4.7[a]	88	17	04	--	01[a]	--	4.1[a]	103	11[a]	03	--	04	--
A3	4.8	17	10	08	--	03[b]	-	4.1[a]	68	10	06[a]	-	03[ab]	-	4.3[a]	18	12[ab]	03	--	04	--
Bh	4.8	114	14	06	--	02[b]	--	4.4[ab]	61	11	02[ab]	--	04[ab]	--	5.1[b]	139	09[ab]	01	--	[illegible]	--
A21	4.0	140	08	01		01[b]	--	4.1[b]	94	11	7[b]	-	01[b]	--	4.1[ab]	186	01[b]	02	--	02	--
								1978-79													
A1	4.1	84	41	11	1.11[a]	07[a]	01	4.5[a]	15	11	05	1.11[a]	08	14	4.0[a]	111	09[a]	04[ab]	1.18[a]	09	21
A3	4.3	11	52	31	1.01[ab]	04[ab]	05	4.4[a]	70	11	01	0.01[b]	08	01	4.4[a]	94	08[b]	14[a]	0.71[b]	05	08
Bh	4.8	148	30	21	0.43[b]	01[b]	01	4.3[a]	240	13	11	0.81[b]	06	01	5.1[b]	215	05[b]	04[b]	0.41[b]	06	06
A21	4.1	286	15	12	0.18[b]	01[b]	01	4.1[b]	91	10	16	0.41[c]	04	04	4.1[b]	131	03[b]	01[b]	0.11[b]	03	03
								1979-80													
A1	4.0[a]	111	24[a]	04	1.10	11	18	4.2	204[a]	91[a]	1.18[ab]	1.81[a]	12	11	4.0[a]	97	08[ab]	04[ab]	1.11[a]	08	06
A2	4.1[a]	152	11[ab]	08	1.91	13	18	4.1	118[ab]	41[ab]	1.49[a]	1.55[ab]	11	08	4.1[a]	111	11[a]	01[b]	1.00[a]	18	06
Bh	4.3[a]	138	16[b]	08	1.04	01	01	4.4	141[ab]	19[bc]	1.21[ab]	0.18[bc]	09	01	4.0[b]	183	07[ab]	04[a]	0.59[b]	01	[illegible]
A21	4.1[b]	344	33[a]	02	0.16	01	04	4.0	101[b]	14[c]	0.10[b]	0.41[c]	04	01	5.1[b]	83	01[b]	02[ab]	0.28[b]	[illegible]	[illegible]

[a]/ Dissimilar superscripts indicate significant differences within each water year (Duncan's, α = .05)

Table 28 Mean annual soil solution chemistry of the Stilson soil by horizon during the control (1977-78), treatment (1978-79), and first post-treatment (1979-80) years

Soil Horizon	Low Intensity Site Preparation (WS-1)							High Intensity Site Preparation (WS-2)							Control (WS-3)						
	pH	Cond	NH_4-N	NO_3-N	Tot N	PO_4-P	Tot-P	pH	Cond	NH_4-N	NO_3-N	Tot-N	PO_4-P	Tot-P	pH	Cond	NH_4-N	NO_3-N	Tot N	PO_4-P	Tot-P
		mmho	ppm						mmho	ppm						mmho	ppm				
	1977-78																				
A1	5 4	43	09^a	03	—	08	—	5 0	45	09	7	—	02	—	4 5	53	09	02	—	03	[illegible]
B1	5 3	60	04^b	03	—	02	—	5 0	66	10	03	—	02	—	5.0	73	11	04	—	[illegible]	—
	1978-79																				
A1	5 1	49	09	20	43	04	05	4 8	50	.08	08	71	03	03	4 4	59	04	03	41	[illegible]	[illegible]
B1	5 3	58	.08	11	33	07	04	5 2	61	11	20	40	03	03	5 3	60	.17	.08	32	[illegible]	[illegible]
	1979-80																				
A1	4 8	94	20	51	64	08	05	4 6^a	124	11	49	73^a	05^a	04^a	4 5	40	07	07	57	[illegible]	[illegible]
B1	5 0	63	.10	.14	30	03	03	5 3^b	08	10	30	.25^b	03^b	02^b	5 2	44	13	04	56	[illegible]	[illegible]

[a] Dissimilar superscripts indicate significant differences within each water year (Duncan's, α = .05)

Table 29 Mean annual soil solution chemistry of the Surrency soil by horizon during the control (1977-78), treatment (1978-79), and first post-treatment (1979-80) years.

Soil Horizon	Low Intensity Site Preparation (WS-1) pH	Cond	NH_4-N	NO_3-N	Tot-N	PO_4-P	Tot P	High Intensity Site Preparation (WS-2) pH	Cond	NH_4-N	NO_3-N	Tot-N	PO_4-P	Tot P	Control (WS-3) pH	Cond	NH_4-N	NO_3-N	Tot N	PO_4-P	Tot-P
		mmho	ppm						mmho	ppm						mmho	ppm				
									1977-78												
Pond Surface	3.8	759^a	.04	.06^a	--	.04	--	4.0^a	167^a	.07	.02^a	--	.07^a	--	4.5	110	.12	.06	--	.02^a	--
A1	4.7	77^b	.07	.01^b	--	.04	--	4.7^b	111^b	.11	T^b	--	.04^a	--	4.7	114	.47	T	--	.06^b	--
A2	4.3	84^b	.14	.03^a	--	.05	--	4.2^{ab}	149^a	.09	T^b	--	.08^a	--	4.1	190	.38	T	--	.08^b	--
									1978-79												
Pond Surface	3.7	177	.19	.04	7.07^a	.10	.11	4.0	107	.16^a	.14	1.92^a	.14^a	.04	4.2	91	.22	.14	2.15	.06^a	.09^a
A1	4.8	103	.05	.10	.88^a	.04	.04	4.2	154	.57^{ab}	.74	.94	.07^b	.08	4.1	143	.14	.12	1.07	.09^a	.07^{ab}
A2	4.1	97	.17	.17	.94^a	.08	.10	4.7	150	.05^b	.74	.73^b	.12^a	.11	4.3	186	.12	.71	1.35	.17^a	.11^b
									1979-80												
Pond Surface	3.7	154	.71	.05^b	1.58	.06	.06	4.0	78	.10	.05	7.21	.05^a	.07	4.3	67	.11	.03	1.37	.03^a	.03^a
A1	4.9	174	.25	.02^b	1.23	.07	.04	4.7	130	.97	.06	.97	.10^b	.06	4.3	142	.40	.54	1.45	.07^a	.07^{ab}
A2	4.1	183	.75	.02^b	1.04	.06	.07	4.7	144	.09	.02	.04	.11^b	.09	4.1	171	.71	.41	1.12	.09^a	.07^b

[a] Dissimilar superscripts indicate significant differences within each water year (Duncan's α = .05)

less intensively prepared watershed (Table 27). The highest concentrations occurred in the A1 horizon during the calibration year, A2 horizon during the treatment year, and B2h horizon during the first post-treatment year. The slow downward migration of NH_4 suggested by this progression may have been impeded by the presence of the spodic horizon. The concentrations of NH_4-N only increased slightly in the A21 despite the relatively large increases which occurred in the horizons above the B2h. This, coupled with the low pHs which inhibited nitrification, provided a mechanism which conserved N following site disturbance.

The Impacts of Management Activities on Soil Solution Chemistry of the Unharvested Cypress Ponds

There were no significant differences in Surrency A1 horizon soil solution chemistry between watersheds, and differences between horizons (Table 29) were consistent from year to year. Inorganic N concentrations might have been expected to be higher in the intensively prepared watershed, which had lower A1 horizon C/N ratios (Table 11), but this difference was not measurable. Increases in NH_4-N or NO_3-N concentrations were not observed following the site preparation activities on the adjacent flatwoods suggesting that lateral flow from the harvested and site prepared areas was not a significant source of N.

Soil Solution as a Predictor of Runoff Water Quality

The increases in soil solution NH_4-N and NO_3-N concentrations which were observed in the Mascotte and Sellsman soils following site preparation were not reflected by similar increases in runoff water NH_4-N and NO_3-N concentrations. Inorganic N concentrations in runoff from

the harvested and site prepared watersheds were either equal to, or less than, those in runoff from the control watershed throughout the study period (Table 30)

Week-to-week fluctuations in runoff water NO_3-N concentrations followed the same patterns that fluctuations in soil solution NO_3-N concentrations followed, even though they did not increase following harvest. Significant correlations between NO_3-N concentrations in runoff from the intensively prepared and control watersheds, and NO_3-N concentrations in soil solution from the Mascotte and Sortrency soils, existed (Table 31). These correlations were probably the result of covariation in both runoff and soil solution NO_3-N concentrations with soil solution NO_3-N concentrations in variable source areas along the drainage network. Most of these source areas may have been located in nearly saturated soils along the edge of cypress pond where they could contribute to surface flow following a few centimeters of precipitation. It would not be surprising that poorly drained Mascotte and very poorly drained Surrency soils would more closely reflect mineralization fluctuations in these areas than the moderately well drained Stilson soils. Ammonium is more strongly absorbed by the soil exchange complex than NO_3 and it was not surprising that the correlations between runoff and soil solution concentrations of it were poorer than they were for NO_3-N

The correlations between soil solution NO_3-N concentrations and runoff water NO_3-N concentrations were not consistently better within watersheds than between watersheds. It can be inferred from these data that changes in runoff water NO_3-N concentrations caused by harvest and site preparation of the flatwoods were small in comparison to the natural variability of these concentrations resulting from changes in microclimatic conditions.

Table 30 Volume-weighted average annual concentrations of NH_4-N and NO_3-N in runoff from the [illegible] and site prepared watersheds during the calibration (1977-78), treatment (1978-79), [illegible] post-treatment (1979-80) water years.[a]

N-form	Low intensity site preparation (WS-2) 1977-78	1978-79	1979-80	High intensity site preparation (WS-2) 1977-78	1978-79	1979-80	Control (WS-3) 1977-78	1978-79	[illegible]
				ppm					
NH_4-N	0.11	0.05*	0.06	0.10	0.12	0.08	0.10	0.22	[illegible]
NO_3-N	0.04	0.03	0.04	0.05	0.07	0.03	0.03	0.04	0.02

[a] Source Riekerk (1981).

*Significantly different from the control during that year (a = .05)

Table 31. Simple correlations of weekly NH_4-N and NO_3-N concentrations in runoff water of each watershed with the concentrations of NH_4-N and NO_3-N in the soil solution (A1 horizon) of Mascotte, Stilson, and Surrency soils during that week for the three year study period

Runoff water	Soil Solution								
	Low intensity site preparation (WS-1)			High intensity site preparation (WS-2)			Control (WS-3)		
	Mascotte	Stilson	Surrency	Mascotte	Stilson	Surrency	Mascotte	Stilson	Surrency
	NH_4-N								
Low intensity site preparation (WS-1)	—	—	—	—	—	—	—		
High intensity site preparation (WS-2)	85[a]	—	—	—	—	—	—	—	—
Control (WS-3)	—	—	—	—	—	[illegible]			—
	NO_3-N								
Low intensity site preparation (WS-1)	—		—	—		—	—		—
High intensity site preparation (WS-2)	90		[illegible]	52		—	88		85
Control (WS-3)	83		78	—		—	82		[illegible]

a/ Only correlations which were significant (α = .01) are indicated

Process Study: Nitrogen Mineralization in the Young Plantations and Undisturbed Forest

Nitrification of the Surface Soil

Soil temperature. Removal of the canopy and insulating litter layer during harvest and site preparation increased surface soil temperatures of both site prepared watersheds during the summer of 1980 when N mineralization processes were being intensively studied (Fig. 21-23). The largest increases were recorded on the intensively prepared area where complete removal of the forest floor during windrowing and disking exposed the mineral soil to direct solar radiation. Maximum daily temperatures at 10 cm depth reached 32-34°C in interbed areas of these plots during July. Daily maxima in the control watershed ranged between 23-26°C during the same period. Much of the litter layer remained intact on the less intensively prepared watershed and maximum soil temperatures at 10 cm depth were generally 1-3°C less than on comparable areas in the intensively prepared watershed.

Peak soil temperatures within the beds were 2-4°C higher than in the interbed areas of the same plot. Two factors were probably responsible for increased bed temperatures: (1) increased surface area exposure which increased absorption of solar radiation, and (2) decreased thermal conductivities and reduced transfer of heat energy to the subsoil. Both the lower soil moistures (see next section) and decreased bulk densities of the beds would be expected to contribute to the reduced thermal conductivities. Destruction of the insulating litter layer during bedding further contributed to higher bed temperatures on the less intensively prepared watershed.

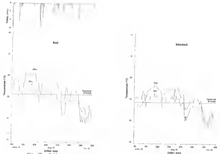

Fig. 22 — Soil temperature at 10 cm depth in a Mascotte soil within the less intensively prepared watershed during the first growing season of the young plantation (1980)

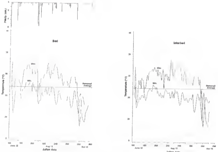

Fig 22 - Soil temperature at 10 cm depth in a Stilson soil within the less intensively prepared watershed during the first growing season of the young plantation (1980)

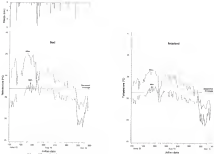

Fig. 23 - Soil temperature at 10 cm depth in a Mascotte soil within the intensively prepared watershed during the first growing season of the young plantation (1980)

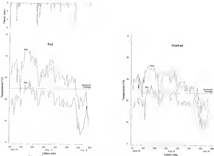

Fig. 24 - Soil temperature at 10 cm depth in a Stilson soil within the intensively prepared watershed during the first growing season of the young plantation (1980).

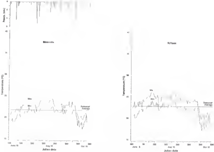

Fig 25 - Soil temperatures at 10 cm depth in Mascotte and Stilson soils within the undisturbed watershed during the first growing season of the plantations on the two treatment watersheds (1980)

Day-to-day fluctuations in temperature maxima and minima were closely related to rainfall patterns. Peak temperatures occurred on clear days during dry periods, and reached a maximum in early July (Julian date = 190). Temperatures at the soil surface (0.2 cm depth) in the intensively prepared watershed were greater than 55°C at this time. Convectional cloud formations generally began forming during the afternoon on a regular basis at about this time and, as a result, peak soil temperatures began to decline. Temperature declines measured at the 10 cm depth averaged 0.5°C/week on the intensively prepared watershed for the remainder of the summer. The rates of decrease in the less intensively prepared and control watersheds were about 0.4°C and 0.2°C/week, respectively. The more rapid declines on the treated watersheds were primarily due to increased shading as a result of vegetation regrowth on areas that experienced only minimal litter insulation. The differences between the recorded maximum and minimum daily temperatures were lower on the plots following each rain as a result of increased heat capacities and thermal conductivities of the wet soil.

Moisture. Surface soil tensions[a/] were higher and more variable on the intensively prepared site than on either the less intensively prepared site or the undisturbed control (Fig. 26-28). The highest tensions occurred within the beds, which approached the measurement limits (about 650 mbar) of at least one of the tensiometer replicates in the plots as six or seven occasions during the summer. The volume

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[a/] Soil water tension is the negative of soil water potential, hence, it has positive values in unsaturated soils. Water potentials will be expressed as tensions throughout this discussion for convenience.

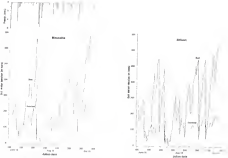

Fig. 26 - Soil water tensions at 5 cm depth in the less intensively prepared watershed during the first growing season of the young plantation (1980)

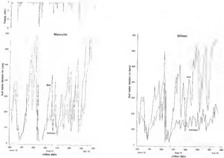

Fig. 27 – Soil water tensions at 5 cm depth in the intensively prepared watershed during the first growing season of the young plantation (1980)

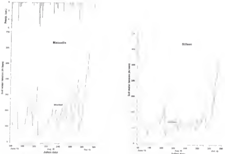

Fig. 28 - Soil water tensions at 5 cm depth in the undisturbed watershed during the first growing season of the plantations as the two treatment watersheds (1980).

presented in Fig. 26-28 are averages of the three replicates and probably underestimate tensions when this occurred.

The seasonal averages at 5 cm depth were 290 and 332 mbar in beds on Mascotte and Stilson soils in the intensively prepared watershed (Fig. 29). Lower tensions, averaging 196 and 147 mbars, occurred in the interbed areas of the plot. These tensions were slightly greater than the 186 and 139 mbar averages recorded at 5 cm depth in the Mascotte and Stilson soils under the undisturbed canopy. Bedded areas within the less intensively prepared watershed were almost as dry as beds in the intensively prepared watershed. In contrast, surface soil in the interbed areas of the less intensively prepared watershed was wetter than soil in the undisturbed forest. Much of the forest floor remained intact in interbed areas of the less intensively prepared watershed. This material was an effective mulch, and evaporation from the soil surface was apparently reduced as a result. The average tensions at 15 cm depth were lower than the 5 cm depth tensions, but appeared to follow the same patterns of fluctuation. Measurements of tensions at greater depths were not replicated and the differences between seasonal averages are probably spurious.

The differences in soil moisture at 5 cm which were observed between the two treatment and the control watersheds were the result of differences in surface evaporation. These values should not be interpreted as representing differences in moisture at greater depths where plant roots were actively absorbing water. Fig. 30 illustrates the sequential drying of a Mascotte soil on each of the three watersheds during a precipitation-free period in late summer. The surface soil of the

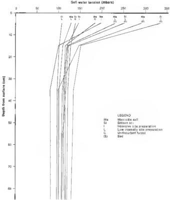

Fig. 29 - Average June through October (1980) soil water tension in an undisturbed forest and in slash pine plantations on intensively and less intensively prepared sites.

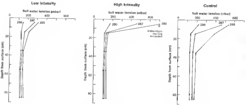

Fig 30 - Soil profile drying during a precipitation free period of late summer (Julian dates 280-295) for Mascar[illegible] soils under slash pine plantations in the treated watershed and under the undisturbed forest

intensively prepared area, which was not heavily vegetated, became very dry during this period and exceeded the measurement limits of the tensiometers. The surface soil of the control watershed did not dry as much as the surface soil of the intensively prepared watershed, but more soil drying occurred at greater depths on this forested watershed due to transpiration from the established vegetation. Both surface evaporation and transpiration were relatively low on the less intensively prepared watershed, and the entire soil profile remained moist during this period.

The summer of 1980 was unusually dry. June through October precipitation was 34% below normal.[a] The water table never approached the soil surface during this period. Consequently, little value could be attached to the bedding operation from the standpoint of increasing root aeration. The data in Fig. 25-30 do not support the hypothesis that understory moisture competition is severe on less intensively prepared sites. That is, seedlings planted on the flor in the less intensively prepared watershed would not appear to have been under more moisture stress than seedlings planted on the intensively prepared site.

Mineralizable Nitrogen Content of the Surface Soil

The quantities of potentially mineralizable N (No) which occurred in these soils (Table 32) were lower than have been reported for agricultural soils (Stanford and Smith, 1972). Strict statistical comparisons concerning the effects of treatment on mineralizable N contents could not be made as the treatment combinations were not replicated

[a] On the basis of monthly averages for Gainesville, Fl.

Table 32 Estimates of potentially mineralizable nitrogen (No) in the surface soil of the harvested and site prepared watersheds and in the control watershed in May of the first post treatment year (first growing season)

Variable	Low Intensity Site Preparation (WS 1)				High Intensity Site Preparation (WS 2)				Control (WS 3)	
	Mascotte		Stilson		Mascotte		Stilson		Mascotte	Stilson
	Interbed	Bed	Interbed	Bed	Interbed	Bed	Interbed	Bed	Interbed	Interbed
No (ppm)	31[a]	88	31	42	34	89	38	41	21	30
No (g/m²)[b]	8 8	11 8	7 7	9 7	8 5	13 6	9 7	10 1	4 5	7 2
k(days)	0010	0288	0283	0244	0287	0287	0248	0288	0271	0268
	(± 0030)[c]	(± 0064)	(± 0040)	(± 0013)	(± 0013)	(± 0088)	(± 00373	(± 00553	(± 0087)	(± 0026)
Range in r² of predictor equations	83-1 00	92 98	86 1.00	82 88	97-1 00	93-1 00	98-1 00	82 1 90	93-1 00	95-1 00

[a] Plot means based on five separately analyzed samples

[b] To 20 cm depth using bulk densities presented in Tables 18 and 25

[c] Standard deviation of plot values

Nevertheless, a clear pattern existed in which mineralizable N increased on all harvested and site prepared plots. This was most evident in the beds where most of this increase can be attributed to physical increases in the depth of N-rich surface soil and to the incorporation of partially decomposed organic material into the soil. Increases in mineralizable N were not confined to the beds, but also occurred within the interbed areas of the plot. It is not difficult to explain these increases in the less intensively prepared watershed where large quantities of logging slash were left on the site. However, the increase of mineralizable N content in the intensively prepared watershed requires further explanation. Almost all logging slash and most of the forest floor was either burned or scraped from the site during windrowing. Thus, the increase in mineralizable N must have been the result of a change in the form of N left on the planting surface. Some of this change may have occurred as the result of stimulating microbial decomposition of resistant materials by mixing fresh materials into the soil during disk harrowing. This process has been termed the "priming effect" and has been widely reported (Harmsen and Kolenbrander, 1965). Repeated drying and rewetting has also been shown to stimulate N mineralization. This occurs as a result of amino acid release from the decomposition of microorganisms killed during the drying process (Lund and Gøksyr, 1980). This cycle involved greater fluctuations on the intensively prepared watershed than on the control watershed and the amounts of N-containing amino acids, or other readily mineralizable compounds, may have been increased despite a lower overall quantity of carbonaceous substrate.

The pools of mineralizable N were not large in comparison to total N contents, and they represented less than 10% of the total N reserves

of the surface soil on all sites. Thus there would appear to be an ample source of soil N with which the pool of mineralizable N could be replenished. However, it can be postulated that the N in litter, residual slash, and other fresh detritus is disproportionately important for maintaining the pool of mineralizable N. On the less intensively prepared watershed there was twice as much mineralizable N in litter plus slash as there was in the pool of mineralizable N at the start of the first growing season. There was only 1/10 as much in the intensively prepared watershed. If the above hypothesis is correct, there should be a measurable decrease in the quantities of mineralizable N in the intensively prepared watershed following a period of relatively rapid mineralization.

The data necessary to confirm or reject the above hypothesis are not yet available for this research area. However, data which seems to confirm this hypothesis were reported by Burger (1979). Burger determined the mineralizable N content of the surface soil horizon of harvested, site prepared, and regenerated flatwoods sites during the second growing season (Table 33). Burger worked on soils similar to the Mascotte soil and his No value of 25 for the undisturbed forest was not very different from the No value of 21 determined for the Mascotte soil in the present study. The No value of 18 ppm which Burger reported for the harvested, windrowed, harrowed, and bedded site was significantly lower than the value for the control site. A similar reduction was not observed on the site which was prepared by chopping and bedding which left large quantities of slash on the prepared surface.

Table [illegible]. The mineralizable nitrogen content of harvested, site prepared, and regenerated flatwoods soils (unbedded areas) during the second growing season of the young plantation [a]

	Site preparation method		
	Windrowed, harrowed, and bedded	Chopped only	Undisturbed control
Nm (ppm)[b]	18^a	23^b	25^b
Nm (g/m^2)	44^a	59	59

[a] Source Burger (1979)

[b] Dissimilar superscripts indicate significant differences (α = .05)

Predicted N Mineralization and Observed N Leaching During the First Growing Season

Prediction of mineralized N. An attempt was made to quantify N mineralization and verify that N mineralization rates were rapid enough to produce the postulated decrease in the mineralizable N content of the intensively prepared watershed. The quantities of N mineralized from May through October of the first growing season (1980) were predicted on the basis of measured soil temperatures (10 cm) and moistures (5 cm). The mean decay rate constant determined by incubation at 35°C ($k_{35°C}$) was adjusted for daily changes in temperature (k_t) using Eq. [6]

$$k_t = k_{35°C} \times (\exp[(\ln 1.9)(35°C - MDT)/10]) \qquad [6]$$

Eq. [6] was derived from the definition of the temperature coefficient where MDT = mean daily temperature at 10 cm, and the Q_{10} value = 1.9. A Q_{10} value of 1.9, rather than 2.0, was used on the basis of work in forest soils under conifers reported by Powers (1980). It provided a slightly more conservative estimate of changes in mineralization rate due to temperature changes.

Mineralization occurs at maximum rates near field capacity (Sommers et al., 1981). It was assumed that optimal moisture conditions were obtained during the incubation study, and that the measured mineralization rates defined the maximum at that temperature (35°C) and field capacity. In fact, the control of soil moisture during the incubation study was not rigid enough to insure that optimal conditions were achieved. The mineralization rates were probably slightly less than optimal and, thus, they provided a somewhat conservative k value. The

decrease in decomposition from this assumed optimal moisture condition to wetter and drier conditions was approximated by adjusting the mineralization rate constant determined in Eq. [6] for moisture (k_{m}) using the relationship of Eq. [1] on page 31. Eq. [1] was based on N mineralization from soils of various textures and might tend to predict higher mineralization rates in dry sands than existed. However, the periods when the soils were dry were of shorter duration than wet periods and no further attempt was made to refine this relationship. Daily mineralization was calculated by substituting the adjusted mineralization rate constant into Eq. [7] and solving for cumulative mineralization (Nt) for each day. The original value of No was set equal to average values for the plot (Table 32) and incrementally reduced by previous values of Nt for successive days.

$$Nt = No\ [1-\exp(-k_{m}t) \qquad [7]$$

The predicted quantities of N mineralized during the first growing season (Julian dates 162-295) are presented in Table 34. Predicted mineralization was highest on beds in the intensively prepared watershed. Values predicted for the beds of the less intensively prepared watershed were almost as high. The interbed values were lower on both watersheds, reflecting lower initial values of No (Table 34) and lower soil temperatures. The differences were larger on the less intensively prepared watershed where the differences between mineralizable N content and temperature tended to be greater. The lowest quantities of mineralizable N were predicted for the control watershed where initial values of mineralizable N and soil temperature were lowest. These quantities approached or exceeded 30% of the total mineralizable N content of the surface soil on both harvested and prepared watersheds and were only slightly lower on the control watershed.

Table 34 Predicted N mineralization (NH_4-N plus NO_3-N) in the surface 20 cm of soil under young plantations of the two treatment watersheds and under the undisturbed forest during the first growing season (Julian dates 162-295).

Mineralized N	Low intensity site preparation (WS-1)				High intensity site preparation (WS-2)				Control (WS-3)	
	Mascotte		Stilson		Mascotte		Stilson		Mascotte	Stilson
	I	B[a]	I	B	I	B	I	B	I	I
N (ppm)	16	34	16	26	20	39	21	29	10	15
N (g/m^2)[b]	3.5	6.8	3.9	6.0	4.9	8.8	5.3	6.8	2.2	3.6

[a] Interbed (I) and bed (B) areas.

[b] Calculated on the basis of bulk densities in Tables 17 and 21.

The estimates of N mineralization (Table 34) were based on the assumption that there were no interactions between temperature and moisture effects and that the decay rate was constant. This was probably an oversimplification. Cassman and Munns (1980) have demonstrated that there is an interaction between temperature and moisture. The decay constant (k) is a dynamic parameter which changes as the relative amounts of labile and resistant fractions of organic substrate change (Hunt, 1977).

The use of the soil temperature and moisture measurements made at one point in the surface soil was also an oversimplification as both changed within the 20 cm depth under consideration. Most organic material occurred at or near the surface of the soil and it was believed that soil moisture measurements at five cm depth would reflect the decomposition and mineralization of this material more accurately than an average of the 5 and 15 cm measurements. The soil temperatures at 10 cm depth were lower than temperatures nearer the surface where decomposition was probably most active and provided conservative estimates of mineralization. Thus, the values presented in Table 34 represent only a rough approximation of N mineralization. Nevertheless, they do indicate that much of the readily mineralizable N present at the start of the growing season should have been mineralized by fall.

Observed N mineralization. The quantities of inorganic N (NH_4-N plus NO_3-N) which were leached from the soil surface (Table 35) were an order of magnitude lower than the predicted quantities. The standard errors of the mean for the seasonal totals were large, ranging from 30% to 80% of the reported totals, thus, the actual N leaching may have been larger

Table 35 Leaching of inorganic N (NH_4-N plus NO_3-N) from the surface 20 cm of soil under young plantations of the two treatment watersheds and under the undisturbed forest during the first growing season (Julian dates 162-245)

Observed N leaching	Low intensity site preparation (WS-1)				High intensity site preparation (WS-2)				Control (WS-3)	
	Mascotte		Stilson		Mascotte		Stilson		Mascotte	Stilson
	I	B [a]	I	B	I	B	I	B	I	I
N (ppm)	0.6	1.0	1.9	3.5	3.6	15.5	1.3	2.4	0.3	0.3
N (g/m^2) [b]	0.14	0.21	0.48	0.80	0.87	3.50	0.33	0.58	0.07	0.08

[a] Interbed (I) and Bed (B) areas

[b] Calculated on the basis of bulk densities in Tables 17 and 21

Nevertheless, these underestimates could account for only a minor portion of the absolute difference between predicted mineralization and observed N leaching.

The infrequency of large rainfall events which could leach toxic metabolites produced during microbial respiration from the soil may have contributed to the low N leaching. Build-up of such substances has been suggested as a cause for decreased N mineralization in incubation experiments (Harmsen and Kolenbrander, 1965). Furthermore, much of the mineralized N that was produced may have been remetabolized by microbes, absorbed by plants, adsorbed on the soil exchange complex, or denitrified and was not leached by percolating water. Thus, it appears that little N was leached from these soils even though a relatively large amount may have been mineralized.

Impacts of Intensive Forest Management on Site Productivity

Nutrient Budgets of the Harvested and Site Prepared Watersheds

The exports and displacements of N, P, and K during the harvest and site preparation of the less intensively prepared and the intensively prepared watersheds are presented in Fig. 31 and Fig. 32, respectively. Data for runoff losses are those of Riekerk (1981). Deep percolation losses were estimated from monthly leakage losses[a] and mean monthly NH_4-N plus NO_3-N and PO_4-P concentrations of soil solution from the lowest soil horizon sampled (approximately 1 m deep). Harvest removals, and displacements from the soil surface during site preparation, were as reported in previous sections.

[a] H. Riekerk, republished data

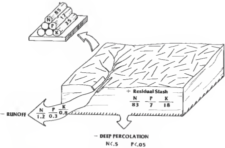

Fig. 31 - Nutrient redistribution and export from a flatwoods forest following shortwood harvest and low intensity site preparation (all values in kg/ha during the treatment year)

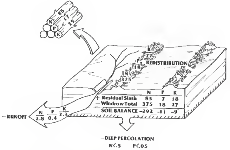

Fig. 32 – Nutrient redistribution and export from a flatwoods forest following mechanical tree-length harvest and intensive site preparation (all values in kg/ha during the treatment year).

The only significant loss of nutrients on the less intensively prepared watershed (Fig. 31) was associated with harvest removals. The 85 kg/ha N, 17 kg/ha P, and 25 kg/ha K removed during harvest comprised about 50% of the respective totals of these nutrients in the above-ground tree biomass. Nutrients in the needles, branches, and understory vegetation were added to the forest floor resulting in a positive soil balance. Runoff and deep leaching losses during the treatment year were insignificant in comparison to harvest removals, totaling less than 2 kg/ha of N and 0.5 kg/ha of P, respectively.

The nutrient budget of the intensively prepared watershed was quite different (Fig. 32). Although harvest removals and dissolved nutrient losses were about the same as on the less intensively prepared watershed, significant quantities of nutrients were also displaced from the interwindrow (growing) surface during the windrowing operation. The 373 kg/ha N and 17.7 kg/ha P localized in the windrows were equivalent to removal of these nutrients in 3 bolewood harvests. The total quantity of N and P removed from the growing surface were equivalent to losses of 23.2 and 1.2 kg ha^{-1} yr^{-1}, respectively, over a 20 year rotation. These losses far exceed precipitation inputs (Table 2) and could result in an overall decline in fertility over much of the growing surface.

Short Term Impacts of Intensive Site Preparation

Seedling survival and growth were better on the intensively prepared watershed than they were on the less intensively prepared watershed (Table 36). These differences were probably due to a number of factors. For example, survival appeared to be lower on the less intensively prepared watershed wherever residual slash and litter were

Table [illegible]. First year survival, height, and foliar N concentrations of slash pine seedlings planted on the treatment watersheds a/

Variable	Low intensity site preparation (WS-1)		High intensity site preparation (WS-2)	
	Mascotte	Stilson	Mascotte	Stilson
Survival (%)	78.8	73.3	87.8	90.6
Height (cm)	29.9	31.7	33.5	36.4
Foliar N (%)				
Vigorous seedlings	1.18 b/		1.39	
Mildly chlorotic seedlings	0.87		1.08	
Severely chlorotic seedlings	0.57		0.83	
Mean for watershed	0.92		1.18	

a/ Source: IMPAC Progress Report, FY 80. Task IV. Univ. of Florida, School of Forest Resources and Conservation, Gainesville

b/ Mean for watershed.

particularly heavy. Beds within these latter areas contained high amounts of organic debris and contact between seedling roots and mineral soil was poor, thus, resulting in excessive root drying. Other factors, such as increased weed competition, disease incidence, or insect attack may have reduced seedling survival on the less intensively prepared watershed but data are not available to support these contentions.

Nitrogen nutrition during the first year was improved by intensive site preparation. Overall foliar N concentrations, and the concentrations of foliar N in individual vigor classes, were higher in seedlings of the intensively prepared watershed than they were in seedlings of the less intensively prepared watershed. These increased N concentrations were consistent with the higher soil solution N concentrations, higher mineralizable N contents, and more rapid N mineralization observed in this watershed.

Improved N availability in the interwindrow areas of the intensively prepared watersheds appeared temporary. It resulted from soil mixing and an increase in surface soil temperatures, both of which promoted microbial activity and mineralization of those organic fractions most readily mineralized. Little fresh detritus remained in the surface soil of this watershed, thus, the pools of mineralizable N would be expected to decrease without inputs of N such as would come from decomposition of these materials. The pools of mineralizable N, and N mineralization rates, in the less intensively prepared watershed were almost as large as they were in the intensively prepared watershed. However, the quantities of litter plus slash contained in the surface soil of this watershed were 20 times greater than in the surface soil of the intensively

prepared watershed. Slow decomposition of this material should contribute to the pool of mineralizable N for a number of years and declines in N availability would not occur as rapidly on this watershed as they would in the intensively prepared watershed. These declines in mineralizable N would not continue indefinitely, but would stabilize as soon as litterfall inputs from vegetation regrowth became significant.

SUMMARY AND CONCLUSIONS

The impacts of intensive and less intensive systems of forest management on nutrient distribution and mobilization were investigated on three flatwoods forests following harvest and site preparation of two of the watersheds in north-central Florida. Two soils, an Ultic Haplaquod (Mascotte) and a Arenic Plinthic Paleudult (Stilson), characterized the harvested area. The intensively treated watershed was harvested by a feller-buncher, delimbed in a delimbing gate, and the trees moved full-length to a yarding area by rubber-tired skidders. The site was prepared for planting by chopping, lighterwood stumping, burning, windrowing, disking, and bedding operations. The less intensively treated watershed was logged by two-man logging crews using chain saws. Felled trees were delimbed, bucked to 1.2 m lengths, and hand stacked on pallets near the spot they were felled. Residual vegetation and slash were broken up by double chopping, and the area was bedded prior to planting.

Nutrient removal associated with the bolewood harvests was similar on both sites. Estimated average removals of N, P, K, Ca, and Mg were 85, 17, 25, 102, and 19 kg/ha, respectively. Analyses of nutrient distribution in the standing biomass indicated that complete above-ground harvest would increase these removals by less than 50%. An additional 373 kg/ha N, 18 kg/ha P, 27 kg/ha K, 163 kg/ha Ca, and 41 kg/ha Mg were removed from most of the growing surface of the intensively prepared watershed by the windrowing operation. This removal

was associated with the large quantities of soil and fine organic materials displaced in the windrow by tractor-mounted blading. Windrows of average cross section contained 10 times greater weights of soil than either coarse wood or fine woody materials.

No differences in the nutrient content of the surface mineral soil were detected as a result of harvesting and site preparation. The quantities of nutrients in litter and residual slash were, however, severely depleted on the intensively prepared (bladed) site. Slash and litter storage of N, P, and K on the intensively prepared site averaged only 22, 1, and 1 kg/ha, respectively. Similar storages on the less intensively prepared site were almost an order of magnitude larger.

Bedding localized nutrients into the seedling rooting zone on both of the harvested and site prepared watersheds. The quantities of N, P, and K in the beds were 50% greater than the contents of these nutrients in the forest floor and A1 horizon of unbedded areas of the site. Most of this increase was due to increases in the quantity (depth) of the surface soil materials in beds, although some increases in nutrient concentrations were also noted.

Increases in inorganic N concentrations in the soil solution occurred on both watersheds during the spring following harvest. The concentrations remained higher than in the control watershed throughout the treatment year and first growing season. The dominant N forms differed between the two soils series investigated. Peak NH_4-N concentrations reached 2.1 ppm in the intensively prepared Mascotte soils during the first growing season, but did not exceed 1.0 ppm in the Stilson soil. In contrast, NO_3-N peaks were higher and more common

than NH_4-N peaks in Stilson soils and they reached a maximum of 4.3 ppm during the first growing season. Ammoniacal N was the dominant N form in Mascotte soils because the high acidity of this soil inhibited nitrification. Stilson soil pH values were higher and nitrification was not as inhibited as in the Mascotte soil. The magnitude of these peaks was consistently higher in the bedded areas than in the interbed areas. No statistically significant increases in PO_4-P concentrations were observed following harvest or site preparation activities.

The concentrations of N in surface runoff did not increase above control levels on either treatment watershed despite the increased soil solution levels. It was suggested that variable source areas for watershed runoff were localized around the edges of cypress ponds which were not harvested and did not respond to harvest of the adjacent flatwoods with increased soil solution N concentrations.

The contents of mineralizable N in the surface 20 cm of soil were determined in May of the first post-treatment year when planted seedlings were in their first growing season. Quantities of mineralizable N in both the bedded and interbed areas of both harvested and prepared sites were greater than in the surface soil under an undisturbed forest. These increases resulted from additions of organic material to the soil as logging slash (less intensively prepared watershed) and increases in the portion of total soil N which was in a readily mineralizable form (less intensively prepared and intensively prepared watersheds). The rate at which these materials would be mineralized during the first growing season was predicted using previously determined temperature, moisture, and mineralization rate relationships and daily measurements of soil temperature and moisture. The quantities of inorganic N leached

from the surface soil were simultaneously measured using *in situ* micro-lysimeters. The predicted rates of mineralization approached 50% of the initial mineralizable N content of the surface soil on both the treated and control watersheds. The amounts of N leached from the surface soil were from about 2% to < 40% of that predicted to have been mineralized.

Analyses of nutrient exports from the treatment watersheds indicated that harvest removals were the major source of nutrient loss. These removals were not excessive and would probably not, in themselves, result in site productivity declines. Nutrient displacements during windrowing of the intensively prepared watersheds were large. Three times more N, and as much P, K, Ca, and Mg were displaced from the interwindrow surface as were removed in harvest alone. Natural mechanisms for returning these nutrients to the interwindrow area are slow and nutrients lost by windrowing would probably not be replaced during a rotation period. Harvest removals plus windrowing displacement could combine to significantly reduce the site productivity of the interwindrow area of the intensively prepared watershed.

Seedling survival and first year growth were better on the intensively prepared watershed than on the less intensively prepared watershed. Foliar N concentrations were also higher in seedlings from the intensively prepared watershed. The increased N availability indicated by these higher foliar concentrations was consistent with increases observed in soil solution N concentration, mineralizable N content of the surface soil, and predicted N mineralization rates. However, the higher rates of mineralization and N availability observed on the intensively prepared watershed were probably temporary. They will apparently decrease below the levels observed in the less intensively

prepared watershed further into the rotation because there was little detrital material left on the intensively prepared watershed which could contribute to its pool of mineralizable N

If these calculations are correct, one might expect a decline in productivity of second and subsequent pine rotations on sites prepared as intensively as the intensively prepared site of this study unless fertilization or other remedial measures are undertaken

APPENDIX A

SOIL PROFILE DESCRIPTIONS

MASCOTTE SERIES (Ma)

Ultic Haplaquods, sandy, siliceous, thermic

The Mascotte series consists of nearly level, poorly drained soils that are formed in beds of sandy and loamy marine deposits. These soils occur on broad areas of the flatwoods. The water table is within 25 cm of the surface for 1 to 4 months and is at depths of 25 to 100 cm for about 6 months. During the driest seasons, the water table recedes to depths of more than 100 cm.

Mascotte soils have low available water holding capacity to depths of about 10 cm, very low from 10 to 45 cm, high from 45 to 65 cm, low from 65 to 85 cm, and medium below this depth. Permeability is rapid to about 45 cm, moderate from 45 to 65 cm, rapid from 65 to 85 cm, and moderate below this depth. Natural fertility is low in the sandy upper (85 cm) and medium in the sandy clay loam subsoils. Organic matter content is low.

Included within this soil in some areas are small areas of Stilson soils. Also included in a few areas are spodic soils with argillic horizon occurring below 100 cm, and small areas of somewhat poorly drained soils with 100 to 200 cm of sandy texture with a 10 to 20 cm brownish stained layer occurring in the upper part of the subsurface layer. Total inclusions in any one delineation are 15 percent or less.

The natural vegetation of this soil is a forest of slash and longleaf pine, with an understory of waxmyrtle, palmetto, gallberry, briars, pineland threeawn, and other low growing shrubs and grasses. Capability unit IIIw-1; Woodland ordination group 3w1.

<u>Typifying Pedon</u>

HORIZON	DEPTH (cm)	DESCRIPTION
A1	0-10	Very dark gray (10YR 3/?) fine sand; weak crumb structure; very friable, many fine and medium roots, very strongly acid; clear smooth boundary
A2	10-45	Gray (10YR 6/1) fine sand; few fine distinct very dark gray and black streaks; single grained; loose few fine roots, very strongly acid; abrupt smooth boundary
B21h	45-55	Black (5YR 2/1) fine sand, weak medium subangular blocky structure; weakly cemented, firm, common fine roots; many sand grains coated with organic matter, few clean sand grains, very strongly acid; gradual wavy boundary
B22h	55-65	Dark reddish brown (5YR 3/3) fine sand, common course

		distinct mottles of reddish brown (5YR 4/3) weak fine granular structure, firm, few fine roots, many sand grains thinly coated with organic matter, few clean sand grains, very strongly acid, gradual wavy boundary
B3	65-73	Dark brown (10YR 4/3) fine sand with common medium distinct dark reddish brown and reddish brown mottles, weak fine granular structure, very friable, few fine roots; very strongly acid, gradual wavy boundary.
A21	73-85	very pale brown (10YR 7/3) fine sand, common medium faint yellowish brown and gray mottles, single grained, loose, few roots, very strongly acid, abrupt wavy boundary.
B21tg	85-120	light gray (10YR 7/1) sandy clay loam, common coarse distinct brownish yellow mottles, weak medium subangular blocky structure, friable, clay bridging and coatings on sand grains, few thin discontinuous clay films on ped faces or in pores, very strongly acid, gradual wavy boundary.
B22tg	120-200	Light gray (10YR 7/1) sandy clay loam, common fine distinct yellowish brown, and common medium distinct red mottles weak subangular block structure, friable, clay bridging and coatings on sand grains, few discontinuous clay films on faces of peds or in pores, very strongly acid

<u>Range in Characteristics</u>

The solum is more than 125 cm thick. Soil reaction is very strongly through strongly acid.

The A1 horizon is black (N 2/ , 10YR 2/1), very dark gray (N 3/ , 10YR 3/1) or dark gray (N 4/ , 10YR 4/1) Texture is usually sand but range includes fine sand. It is 8 to 15 cm thick. The A2 horizon is gray (10YR 5/1, 6/1), light grayish brown (10YR 6/2), light grey (10YR 7/1, 7/2), or white (10YR 8/1, 8/2) sand or fine sand Thickness is 8 to 40 cm thick.

A thin 3 to 8 cm transitional layer of black (N 2/ , 10YR 2/1), very dark gray (10YR 3/1), very dark greyish brown (10YR 3/2), or dark gray (10YR 4/1) occurs between the base of the A2 and upper part of the B2h horizon in some pedons The texture of this transitional layer is sand or fine sand and many of the sand grains are uncoated. The B2h horizon is black (5YR 2/1, 10YR 2/1), very dark brown (10YR 2/2), dark reddish brown (5YR 2/2, 3/2, 3/3, 3/4), or dark brown (7.5 YR 3/2) sand or fine sand. It is weakly cemented and is 15 to 28 cm thick. Some

pedons have B3 horizon, and where present, it is dark brown (10YR 4/3) or dark yellowish brown (10YR 4/4, 3/4) sand or fine sand, 8 to 15 cm thick.

The A21 horizon is very pale brown (10YR 7/3, 7/4), pale brown (10YR 6/3), light brownish gray (10YR 6/2), greyish brown (10YR 5/2), or light grey (10YR 7/2) with or without mottles of shades of grey, yellow, and brown Texture is sand or fine sand, 5 to 15 cm thick

The B2tg horizon is dark gray (10YR 4/1) grey (N 5/, 6/ , 10YR 6/1) or light gray (10YR 7/1)

PAMLICO SERIES (Pa)

Terric Medisaprists, siliceous, dysic, thermic

The Pamlico series consists of nearly level, poorly drained, organic soils that formed largely from non-woody fibrous hydrophytic plant remains, mixed with some aquatic woody material These soils occur in ponds and swamps within the broad areas of the flatwoods The surface of the soil is covered with water for more than 6 months during most years and the water table is within 25 cm continuously, except during extended dry periods.

Pamlico soils have very high available water capacity to about 65 cm and very low between depths of 65 and 175 cm. Permeability is rapid. Natural fertility is medium Organic matter content is very high in the surface layer and low in the underlying sandy material

Included with this soil are small areas of Surrency variant and Surrency soils. Also, included are a few small areas of Pelham soils Total inclusions in any one delineation are about 20 percent

The natural vegetation of the soil is chiefly cypress, with bay black gum, swamp maple, and areas of water tolerant grasses.

Typifying Pedon

HORIZON	DEPTH (cm)	DESCRIPTION
O1	0-65	Black (10YR 2/1) well decomposed organic material, less than 10 percent fibers when rubbed; weak medium granular structure, common fine and medium roots; very strongly acid, abrupt wavy boundary
IIC	65-200	Light brownish gray (10YR 6/2) sand, with few medium faint grayish brown mottles; single grained, loose, very strongly acid

Range in Characteristics

Depth to the underlying sandy material [illegible]0-73 cm. Fiber content in the top 10 cm of the 01 horiz[illegible] 60-90 percent after rubbing.

PELHAM SERIES (Pa)

Arenic Paleaquults, loamy, siliceous, thermic

The Pelham series consists of nearly level, poorly drained soils that formed in thick beds of loamy marine sediments. These soils occur on broad areas of the flatwoods. The water table is within 25 cm of the surface for 1 to 4 months during most years. During dry seasons, it recedes to depths of more than 100 cm.

Pelham soils have low available water capacity to about 73 cm and medium below this depth. Permeability is rapid to about 73 cm and moderate between depths of 73 and 190 cm. Natural fertility is low in the sandy upper 73 cm and medium in the loamy subsoils. Organic matter content is low.

These soils are poorly suited for most general farm crops. With high level management and proper water control, these soils can produce good yields of adapted special crops. These soils are well suited for improved pastures of adapted grasses and legumes, with proper management.

Included with this soil are small areas of Mascotte and Surrency soils. Also included are some areas where the clay content of the subsoil decreases by more than 20 percent of its maximum within depths of 150 cm and there is a second increase in clay content within 200 cm. Total inclusions in any one delineation are less than 20 percent.

The natural vegetation of this soil is a forest of slash pine, sweetgum, maple, and water oak. The understory is chiefly gallberry, waxmyrtle, briars, holly, and native grasses. Capability unity IVw-1, woodland ordination group 2w2.

Typifying Pedon

HORIZON	DEPTH (cm)	DESCRIPTION
A11	0-10	Very dark gray (10YR 3/1) fine moderate medium granular structure, very friable, common fine roots; very strongly acid, clear smooth boundary

[illegible]	[illegible]	Light brownish gray (10YR 6/2) fine sand, with few fine faint gray mottles, single grained, loose, few fine roots, very strongly acid, clear wavy boundary
[illegible]	[illegible]	Gray (10YR 6/3) fine sand, single grained, loose, few fine roots, very strongly acid, clear wavy boundary
B21tg	73-108	Gray (10YR 5/1) sandy clay loam, with few fine distinct light yellowish brown mottles; moderate medium subangular blocky structure, thin discontinuous clay films on faces of peds, very strongly acid, clear wavy boundary.

Range in Characteristics

The solum ranges from 150 to more than 200 cm

The A1 horizons are dark gray (10YR 4/1, 5Y 4/1) very dark grey (N 3/ , 10YR 3/1) or dark grayish brown (10YR 4/2, 2 5Y 4/2). The A2 horizon is olive yellow (2 5Y 6/6, 6/8), grayish brown (10YR 5/2, 2 5Y 5/2), light yellowish brown (10YR 6/4), or light olive brown (2 5Y 5/4, 5/6) texture is loamy sand or sand.

The B21t and B22t horizons are yellow (10YR 7/6, 2 5 7/8), brownish yellow (10YR 6/6, 6/8) yellowish brown (10YR 5/4, 5/6) or light brownish gray (2 5 6/2, 10YR 6/2), with distinct and prominent mottles of grey brown and red Texture of the B2t is sandy loam or sandy clay loam

STILSON SERIES (St)

Arenic Plinthic Paleudults, loamy siliceous, thermic

The Stilson series consists of nearly level, moderately well drained soils that formed in thick beds of loamy materials. These soils occur as upland areas. A perched watertable is present at 75 to 100 cm depths for several weeks during wet periods

Stilson soils have low available water capacity in the upper 70 cm and medium in the loamy subsoils Permeability is rapid in the upper 70 cm and moderate below that depth. Natural fertility is low in the sandy upper 70 cm and medium in the sandy clay loam subsoils. Organic matter content is low.

Included with this soil in some areas are small areas of Mascotte and Pelham soils. Also, included in a few areas are similar soils with gray mottles within 70 cm

Typifying Pedon

HORIZON	DEPTH (cm)	DESCRIPTION
A1	0–10	Dark gray (10YR 4/1) fine sand; weak fine granular structure, very friable, many fine roots, strongly acid, clear smooth boundary.
A2	10–70	Light yellowish brown (10YR 6/4) fine sand weak fine granular structure, very friable, common fine roots, very strongly acid, clear wavy boundary
B1	70–78	Light yellowish brown (2.5Y 6/4) loamy fine sand, with few fine distinct yellowish brown mottles, weak medium subangular blocky structure, very friable, few fine roots, very strongly acid, gradual wavy boundary.
B21t	78–125	Brownish yellow (10YR 6/6) sandy clay loam, with few fine faint yellowish brown and common medium distinct light gray mottles, moderate medium subangular blocky structure, friable; clay films on ped faces, few pebbles of iron stone; few fine roots, few pores, very strongly acid, gradual wavy boundary
B22t	125–150	Light yellowish brown (10YR 6/4) sandy clay loam, with many coarse distinct light gray, and common medium prominent red mottles, moderate medium subangular block structure, firm, patchy clay films on ped faces, few pebbles of iron stone, about 20% of the red mottles may be plinthite, very strongly acid
B23tg	150–200	Grey (10YR 6/1) sandy clay loam with few fine distinct light yellowish brown and yellowish brown mottles, moderate medium subangular blocky structure, friable; thin discontinuous clay films on ped faces; very strongly acid.

Range in Characteristics

The solum is more than 150 cm thick. Soil reaction is very strongly through strongly acid in reaction

The A horizon is usually sand, but the range includes loamy sand. The A1 and Ap horizons are black (N2/ , 10YR 2/1), very dark gray (N 3/ , 10YR 3/1), or dark gray (N 4/, 10YR 4/1), and 10 to 20 cm thick. Black or very dark gray A1 and AP horizons are 10 to 14 cm thick. The A2 horizon is gray (10YR 5/1, 6/1) light gray (10YR 7/1, 7/2), or light brownish grey (10YR 6/2), with or without mottles in shades of grey, yellow and brown. It is 52 to 88 cm thick.

The B21t horizon is gray (N5. , 6/1 , 10YR 5/1, 6/1 5y 5/1, 6/1), light gray (10YR 7/1, 5Y 7/1), or light brownish gray (10YR 6/2) with or without mottles in shades of gray, yellow and brown. Texture is sandy loam and thickness is 10 to 20 cm. The B22t and B23tg horizons have the same color range as the B21t horizon, with mottles in shades of grey, yellow, brown, and red. Texture of the B22t and B23tg horizons are sandy loam or sandy clay loam. Thickness is 63 to 93 cm thick. Some pedons have B3g horizons, and when present, the color is grey (10YR 5/1, 6/1, 5Y 5/1, 6/1), or light gray (10YR 7/1, 5Y 5/1) sandy loam or sandy clay loam. In some pedons the clay content decreases by 20 percent or more of its maximum in the Btg within depths of 150 cm of the surface, however, in these pedons there is a second increase in clay content between the depths of 150 to 200 cm.

SURRENCY SERIES (Su)

Arenic Umbric Paleaquults, loamy, siliceous, thermic.

The Surrency series consists of nearly level, very poorly drained, soils that formed in beds of loamy marine deposits. These soils occur in wet depressions and swamps within the broad flatwoods area. The water table is within 25 cm of the surface more than 6 months during most years, and in most areas the water is above the surface for 4 months or more annually.

Surrency soils have low available water capacity in the sandy upper 70 cm and medium in the loamy subsoils below. Permeability is rapid to about 70 cm and moderate below this depth. However, internal drainage is slow, impeded by a shallow water table. Natural fertility and organic matter content is high to depths of about 40 cm and low below this depth.

Included with this soil are small spots of soil with similar characteristics but have a brown or dark-brown layer within some part of the subsurface layer. Small spots of soils with 10 to 25 cm of well decomposed organic material on the surface are within some delineations. Also included are small areas of similar soils with sandy subsurface layers to depths of more than 100 cm. Total inclusions in any one delineation are about 20 percent.

The natural vegetation of this soil is chiefly cypress, with gum, bay and scattered slash pine in some areas. Capability unit VIIw-1,

Typifying Pedon

HORIZON	DEPTH (cm)	DESCRIPTION
O1	13-4	Sphagnum moss and leaf litter and roots
O2	4-0	Decomposed organic material
A1	0-30	Black (N2/) loamy sand, weak fine granular structure, very friable, many fine and medium tree and shrub roots, few uncoated sand grains, extremely acid, clear wavy boundary
A2	30-68	Grayish brown (10YR 5/2) fine sand, single grained, loose, few fine and medium roots, many clear sand grains, few sand grains have brown coatings, extremely acid, clear wavy boundary
B21tg	68-120	Gray (10YR 6/1) sandy clay loam, with common medium distinct yellowish brown mottles, moderate medium subangular blocky structure, some clay films on peds friable, few fine roots, very strongly acid; gradual wavy bounday
B22tg	120-200	Light gray (10YR 7/1) sandy clay loam, with common medium and many distinct yellowish brown mottles, moderate medium subangular blocky structure, clay films on ped faces, very friable, very strongly acid

Range in Characteristics

The solum is 150 cm or more thick. Soil reaction is extremely acid through very strongly acid in all horizons

The A1 horizon is black (N2/ , 10YR 2/1), or very dark gray (N 3/ , 10YR 3/1) sand, 25 to 50 cm thick. The A2 horizon is dark gray (10YR 4/1), gray (10YR 5/1, 6/1), light brownish gray (10YR 6/2), grayish brown (10YR 5/2), light gray (10YR 7/1, 7/2), or dark grayish brown (10YR 4/2) sand, 25 to 50 cm thick. Texture of the A horizons range from sand to loamy sand

The B2tg horizon is gray (N 5/ , 6/ , 10YR 5/1, 6/1), or light gray (N7/ , 10YR 7/1) sandy loam or sandy clay loam. Thickness of this horizon ranges from 75 to 85 cm.

SURRENCY VARIANT SERIES (Sr)

[illegible] Umbric Paleaquults, loamy, siliceous, thermic

The Surrency variant series consists of nearly level, very poorly drained soils that formed in thick beds of sandy and loamy marine sediments. These soils occur in ponds within the flatwoods areas. The water table is at depths of less than 25 cm for 6 to 12 months during most years. Most areas are covered with water for 6 months or more annually.

These soils have high available water capacity in the upper 40 cm, very low to low from 40 to 95 cm, and medium below this depth. Permeability is rapid in the sandy upper 95 cm and moderate in the loamy subsoils below. Natural fertility is medium in the upper 40 cm, low from 40 to 95 cm, and medium below. Organic matter content is high in the surface layers and low in the subsurface layers and subsoils.

Included with this soil are small areas of Surrency soils. Also included are small areas with similar characteristics but which lack a brownish layer in some part of the subsurface layer. A few small areas of very poorly drained soils with a subsurface layer that contains more than 1 percent organic matter content and iron content of more than 0.5 percent exist. The center part of the ponds, in some areas mapped as this soil, have a thin 3 to 10 cm covering of well decomposed organic material on the surface. Total inclusions in any one delineation are less than 20 percent.

The natural vegetation of this soil is chiefly cypress. Black gum, bay, and other water tolerant hardwoods occur in a few areas. All of this soil is still in natural vegetation. Capability unit VIIw-1.

Typifying Pedon

HORIZON	DEPTH (cm)	DESCRIPTION
O1	10-2	Organic litter of leaves and twigs
O2	2-0	Decomposed organic material
A1	0-40	Black (N 2/) sand, moderate medium granular structure, very friable, few roots, about 14 percent organic matter content, strongly acid; clear wavy boundary
A2&Bh	40-45	Dark grey (10YR 7/1) sand; single grained, loose, few roots, many clean sand grains, strongly acid, clear wavy boundary

A22	[illegible]	Light grey (10YR 7/1) sand, single grained, loose, few roots; many clean sand grains, strongly acid, clear wavy boundary
B2tg	95-200	Gray (10YR 6/1) light sandy loam, weak fine subangular blocky structure very friable, sand grains well coated with clay, strongly acid, clear wavy boundary

Range in Characteristic

The solum is more than 150 cm thick Soil reaction is extremely through strongly acid in all horizons.

The A1 horizon is black (N 2/ , 10YR 2/1) or very dark grey (N 3/ , 10YR 3/1) sand. Organic matter content is less than 20 percent, ranging from about 4 to 8 percent Thickness of the A1 horizon is 25 to 60 cm. The A2i horizon is grey (10YR 6/1), light brownish grey (10YR 6/2), or light gray sand 0 to 55 cm thick The A2&Bh horizon is dark brown (10YR 4/4), brown (10YR 5/3) or dark grayish brown (10YR 4/2) sand Common to many clean sand grains are in this horizon. It is 10 to 33 cm thick. The A23 horizon is light brownish grey (10YR 6/2), light gray (1)YR 7/2), grayish brown (10YR 5/2), or brown (10YR 5/3) sand, 13 to 58 cm thick. The B2tg horizon is grey (N 5/ , 6/ , 10YR 5/ , 6/1- 2.5Y 5/1, 6/1), with or without mottles in shades of yellow, brown and red Thickness ranges from 25 to over 100 cm Texture ranges from sandy loam through sandy clay loam. Some pedons have a few fine streaks and pockets of sandy material

APPENDIX B

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS PRIOR TO HARVEST AND SITE PREPARATION

Table 37 Average physical and chemical characteristics of the th[illegible] research area prior to harvest and site preparation.

[illegible]	Mesa [illegible]									[illegible]						[illegible]		
	O1	O2	A1	A2	[illegible]	[illegible]	[illegible]	[illegible]	O2	A1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Thickness (cm)	ND	ND	11.3	31.8	20.9	25.1	20.3	ND	ND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bulk density (g/cm^3)	ND	ND	1.0	1.1	1.25	1.20	1.35	ND	ND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
pH [b/]	ND	ND	3.3	[illegible]	3.3	3.2	3.8	ND	ND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Organic matter (%) [c/]	ND	ND	2.3	[illegible]	3.1	[illegible]	0.5	ND	ND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total N (%) [d/]	0.73	0.82	0.03	0.1	0.03	0.01	0.01	0.35	0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C/N ratio	ND	ND	34	30	18	34	26	ND	ND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	13	23
	--total ppm--		[illegible] ppm [e/]					total ppm--		[illegible] ppm				[illegible] ppm		[illegible] ppm		
P	335.8	306.3	3.5	[illegible]	1.1	[illegible]	[illegible]	385.0	323.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	246.1	[illegible]	[illegible]	[illegible]
K	383	383	14	4	3	4	8	366	360	[illegible]	[illegible]	5	5	314	388	8	3	4
Ca	3306	3384	81	31	33	12	18	3839	1856	42	3	17	24	1883	381	38	58	33
Mg	838	596	38	5	8	8	33	686	838	1	5	9	23	883	333	8	5	38
Fe	ND	ND	38	3	82	38	ND	ND	ND	39	13	18	31	ND	ND	18	8	315
Al	ND	ND	38	31	381	256	333	ND	ND	306	338	183	112	ND	ND	298	186	63

[illegible]

APPENDIX C

PLANT TISSUE NUTRIENT CONCENTRATIONS

Table 38 Mean plant tissue nutrient concentrations by species and component

Species	Component	N	P	K	Ca	Mg
		total,(%)				
<u>Gordonia lasianthus</u>	Branch	0.35	0.03	0.22	0.57	0.14
	Foliage	1.14	0.05	0.35	0.78	0.37
<u>Ilex coriacea</u>	Branch	0.31	0.03	0.07	0.34	0.11
	Foliage	0.91	0.05	0.22	0.51	0.34
<u>Ilex glabra</u>	Branch	0.30	0.03	0.09	0.50	0.10
	Foliage	0.99	0.06	0.24	0.63	0.22
<u>Ilex myrtifolia</u>	Bole	0.21	0.01	0.20	0.27	0.09
	Branch	0.54	0.04	0.27	0.65	0.15
	Foliage	1.31	0.05	0.26	0.79	0.42
<u>Lyonia spp</u>	Branch	0.31	0.02	0.11	0.30	0.04
	Foliage	0.84	0.03	0.27	1.20	0.16
<u>Magnolia virginiana</u>	Branch	0.57	0.04	0.21	0.34	0.12
	Foliage	1.83	0.08	0.44	0.72	0.26
<u>Myrica cerifera</u>	Branch	0.49	0.02	0.09	0.68	0.07
	Foliage	1.51	0.04	0.29	1.15	0.26
<u>Nyssa sylvatica</u>	Bole	0.25	0.01	0.07	0.54	0.08
	Branch	0.38	0.03	0.13	0.91	0.12
	Foliage	1.50	0.07	0.34	0.90	0.52
<u>Persea palustris</u>	Bole[a]	0.40	0.04	0.14	0.51	0.06
	Branch	0.40	0.04	0.14	0.51	0.06
	Foliage	1.20	0.07	0.37	0.72	0.13
<u>Pinus elliottii</u>	Bole	0.14	0.03	0.04	0.17	0.03
	Branch	0.24	0.02	0.07	0.27	0.04
	Foliage	0.82	0.04	0.24	0.25	0.12
<u>Serenoa spp.</u>	Foliage	0.74	0.07	0.12	0.17	0.14
<u>Smilax spp</u>	Foliage	0.54	0.03	0.22	0.38	0.06
<u>Taxodium distichum</u>	Bole	0.26	0.02	0.06	0.26	0.04
	Branch	0.52	0.03	0.11	0.89	0.07
	Foliage	1.14	0.06	0.23	1.02	0.26

[illegible]

Species	Component	N	P	K	Ca	Mg
		---------	---------	total,(%)	---------	---------
Vaccinium spp	Branch	0.36	0.03	0.16	0.60	0.06
	Foliage	1.03	0.05	0.19	0.94	0.26
Vitis spp	Branch	0.61	0.04	0.12	0.44	0.14
	Foliage	1.40	0.09	0.27	1.05	0.47
Miscellaneous[b]	Foliage	1.00	0.06	0.25	0.83	0.29
	Branch	0.43	0.03	0.14	0.50	0.10

[a] Bole assumed equal to branch for computation of nutrient contents in Tables 12-14

[b] Composite sample of unidentified shrubs or shrubs which comprised only a small portion of total biomass

APPENDIX D

STATISTICAL DESIGNS AND SUPPORTING ANALYSES

Table 39 Analysis of variance used to analyze the effects of harvest and site preparation (exclusive of bedding) on flatwoods soil, litter, and soil solution characteristics

Source	df		
	Group 1[a/]	Group 2[b/]	Group 3[c/]
Treatments			
Site preparation	2	2	2
Soil	1	1	1
Site preparation x soil	2	2	2
Experimental error	12	12	12
Total	17	17	17
Subsampling error	72	162	Variable[d/]

[a/] Includes soil and litter N, P, K, Ca, Mg, Fe, and Al concentrations and contents, litter weight, soil pH, soil organic matter, and soil C/N ratio

[b/] Includes soil bulk density and depth

[c/] For soil solution pH, conductivity, NH_4-N, NO_3-N, PO_4-P, total N and total P concentrations

[d/] Degrees of freedom for subsampling error ranged from 0 for analyses by Julian date to 148 depending on the element and water year under consideration

Table 14. Split plot ana[illegible] bedding on flatwoods soi[illegible] characteristics.

Source	df Group 1[a]	df Group 2[b]	df Group 3[c]
Main plot treatments			
Site preparation	1	1	1
Soil	1	1	1
Site preparation x soil	1	1	1
Error a	8	8	8
Subplot treatments			
Bedding	1	1	1
Bedding x soil	1	1	1
Bedding x site preparation	1	1	1
Bedding x soil x site preparation	1	1	1
Error b	8	8	8
Total	23	23	23
Subsampling error	96	216	Variable[d]

[a] Includes soil and litter N, P, K, Ca, Mg, Fe, and Al concentrations and contents, litter weight, soil pH, soil organic matter, and soil C/N ratio

[b] Includes soil bulk density, soil depth, bed width

[c] For soil solution pH, conductivity, NH_4-N, NO_3-N, PO_4-P, total N, and total P concentrations

[d] Ranged from 136 to 224 for analysis by water year depending on the parameter being analyzed and the year under consideration

Table 41 Analysis of variance used to analyze the effects of harvest and site preparation of the adjacent flatwoods on the soil solution chemistry of the Surrency soils.

Source	df
Treatments	
Site preparation	2
Experimental error	6
Total	8
Subsampling error	Variable[a]

[a] Degrees of freedom for subsampling error ranged from 86 to 226 for analysis by water year depending on the element being analyzed and the year under consideration.

Table [illegible]. Analysis of variance [illegible] solutions from different [illegible] each soil type

Source	df		
	Mascatta	Stilson	[illegible]
Treatments			
Horizon	3	1	2[a]
Experimental error	8	4	6
Total	11	5	8
Subsampling error	Variable[b]	Variable	Variable

[a] Includes water from pond surface.

[b] Subsampling error ranged from 43 to 193 depending on the element being analyzed, soil type, and water year under consideration.

Table 43. Treatment comparisons of surface [illegible] date for use with Fig. 11-20.

Julian date	Main effects					Mascotte					Stilson				
	pH	Cond	NH_4-N	NO_3-N	PO_4-P	pH	Cond	NH_4-N	NO_3-N	PO_4-P	pH	Cond	NH_4-N	NO_3-N	PO_4-P
1977-78															
306															
334															
362				I					TC						
25															
55															
81		TC													
109															
136															
164															
200															
215	TC														
249	TC/TT														
[illegible]															
349															
363															
5															
12															
19															
26															
33															
40															
47															
54															
61															
82															
92															
101															
107															

Table 43. Continued

Julian date	Main effects pH	Cond	NH_4-N	NO_3-N	PO_4-P	Mascotte pH	Cond	NH_4-N	NO_3-N	PO_4-P	Stilson pH	Cond	NH_4-N	NO_3-N	PO_4-P
115															
129															
145															
153															
160															
180															
187															
194															
201															
215															
264															
1979-80															
334															
341			TT	I					TC/TT					TC/TT	
4			I					TC/TT							
11	I					TT					TT				
32		TC/TT	TT												
39	I	TC/TT				TC/TT									
60		TT													
95			I					TC/TT							
106					I					[illegible]					TC/TT
135															
151				I					TC/TT						
170															
184															
283		I						TC/TT					TC/TT		
311															
347		TT													

I - Indicates treatment x soil interaction
TC - Treatment watersheds significantly different from control (a= 05)
TT - Difference between the two harvested and site prepared watersheds significant ([illegible]

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BIOGRAPHICAL SKETCH

Lawrence Anthony Morris, son of Edwin Joseph Morris and Helen Mary Waliki, was born on May 20, 1952, in New Haven, Connecticut. He lived and attended school in Hamden, Connecticut, until 1970 when he graduated from Hamden High School and entered the University of Maine. He received his Bachelor of Science degree in forestry with honors from that institution in 1974. He entered graduate school at the State University of New York, College of Environmental Science and Forestry that same year and completed his Master of Science degree in 1977. Mr. Morris moved to Florida and was employed as a Research Assistant at the University of Florida, School of Forest Resources and Conservation, until September of 1978 when he returned to graduate school in the Department of Soil Science. He was awarded his Doctor of Philosophy degree in soil science in December of 1981.

Mr. Morris is a member of the American Association for the Advancement of Science, Soil Science Society of America, Sigma Xi, Alpha Zeta, and Xi Sigma Pi. He has been married to Sue Ann Lawrence since June of 1977. They are blessed with a nine month old son, Arthur Edwin Morris.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dr. William L. Pritchett, Chairman
Professor of Soil Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Robert S. Mansell

Dr. Robert S. Mansell
Professor of Soil Science

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Dr. Allen Overman
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy

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